J. Coat. Technol. Res., **13** (1) 133–141, 2016
DOI 10.1007/s11998-015-9734-8

Effect of the type of illumination on perceived blackness of automotive finishes

R. Jafari, F. Ameri, N. Khalili

Abstract The blackness perception of six black automotive finishes was evaluated under three different illumination conditions: unidirectional illumination, diffuse illumination and light booth condition. The metallic black panels with approximately the same appearance attributes, specular gloss, distinctness of image and orange peel, were selected to minimize the effect of total appearance factors on perceived blackness. Fourteen non-expert observers (5 males and 9 females) assessed the black panels while their normal color vision was examined by the Ishihara test. The pair comparison method was applied to rank the metallic black panels based on their perceived blackness. The results showed that under the diffuse illumination condition, a good correlation was observed between the lightness attribute of metallic black panels and their visual scales, where a decrease of the L^* value leads to an increase of perceived blackness. In addition, observers assessed the darkest and the most neutral panel as the blackest sample under the three applied illumination conditions.

Keywords Blackness perception, Automotive finishes, Appearance, Illumination, Visual assessment

Introduction

The expression of ''total appearance'' was first defined in a food context while considering the food's color, taste, smell and mouth consistency.[1,2] Later, the concept of total appearance was applied to the visual appearance of objects by regarding their color and texture.[2–4]

R. Jafari (✉), F. Ameri, N. Khalili
Department of Color Physics, Institute for Color Science and Technology, P.O. Box: 16765-654, Tehran, Iran
e-mail: jafari-ra@icrc.ac.ir

The importance of total appearance is related to its key role in many markets. In fact, the judgment of consumers about the quality of many products is strongly influenced by their surface appearance.[5–7] So, the measurement of appearance is very important for many industries when developing and marketing their products.[5,7] Today, the automotive industries play a very important role in the world's commercial markets. Therefore, it is essential for such industries to quality control the total appearance of their products.[6]

Based on some complex interactions between the incident light and an object, the surface appearance is characterized by color attributes and geometric properties.[8,9] For effect coatings like automotive finishes, the geometric attributes can be defined as specular gloss, distinctness of image (DOI), orange peel (OP), etc.[5,7,10] There has been some research which tried to relate the results of instrumentally measured appearance parameters of automotive finishes in terms of gloss, OP and DOI with those achieved from visual assessment experiments.[5,7] In addition, the effect of texture and color on the evaluation of the appearance of effect coatings has also been investigated.[4,11] It seems that there has not been any research to individually investigate the color perception of automotive finishes, although in the automotive market, the color of automobiles plays a very important role in customers' decisions to buy a car. According to a report published by PPG Industries (Pittsburgh, PA, USA) white was ranked as the first choice color for cars, with silver and black ranked as second choices. For example, in North America, the most popular color was defined as white (21%) followed by black (19%), gray (17%) and silver (15%). However, in South America, silver (33%), white (29%) and black (13%), respectively, led in popularity. For luxury vehicles, it seems that metallic black and pearl white were the most popular finishes in 2013.[12]

From the color physics point of view, blacks and whites are defined as achromatic over the lightness axis of color spaces.[13] In contrast to the many studies on white samples, only a few researchers have investigated the spectral and colorimetric attributes of black samples.[14–22] Jafari et al. investigated the spectral behaviors of black papers and fabrics in different reduced spaces, i.e., R, 1/R and K/S. They showed that, depending on the type of samples and the applied spectral domains, blacks could be satisfactorily described in a two- or three-dimensional subspace.[14] There have also been some attempts to construct a metric to assess the perceived blackness of materials based on the colorimetric attributes of black papers and fabrics.[15–17] In this way, Westland et al. introduced their blackness indices inspired by a whiteness formula and considering different concepts related to blackness perception.[15] On the other hand, Clonts and her coworkers expressed their ranking and rating models by considering the hue attribute or the chroma/hue properties of black objects, respectively.[16,17] In addition, the effects of lightness, hue and chroma were investigated on blackness perception and preference.[18–22] The results showed that observers evaluate more neutral samples as the blackest while they prefer blacks with a cyanish-bluish tint effect.[16,17,22] Moreover, the nationality and the gender of observers were explored as cultural parameters that may affect the blackness preference.[18–20]

The above-mentioned researchers investigated the blackness perception of a variety of black samples, i.e., printed black papers, printed and dyed black fabrics, Munsell samples and simulated blacks on monitors.[15–22] However, until now, no research has evaluated the perceived blackness of effect coatings.

Regarding the vital role of the black color in the automotive market, this paper investigates the blackness perception of automotive finishes. Because of the influence of the lighting conditions on the evaluation of the appearance of effect coatings,[4,11] three illumination conditions, i.e., diffuse illumination condition, unidirectional illumination and the light booth, are considered to assess the perceived blackness of metallic black panels.

Experimental

Samples preparation

In order to prepare paint panels with nearly the same appearance, all samples were prepared at the Iran Khodro car manufacturing company. Before treating them with zinc phosphate, the surfaces of all the steel panels were preliminary washed and degreased. Phosphate substrates were then coated with an epoxy-amine electrodeposited layer with a thickness of 20 μm. In the next step, a polyester/melamine primer surfacer was applied over the electrocoated substrates. The thickness of the primer layer was about 30–40 μm. Then, the acrylic-melamine basecoat was applied on the primer layer. After a short flash-off time, by applying the wet-on-wet method, an identical acrylic/melamine clear coat was applied over the basecoat. The base and clear coats with thicknesses of 12–15 and 40–50 μm, respectively, were simultaneously cured at 140°C for 20 min. In this way, 70 metallic black panels with a size of 20×10 cm^2 were prepared, while the metallic black paints contained fine silver dollar grades of non-leafing aluminum flakes which resulted in brighter and higher chroma.

Samples selection

The 70 prepared metallic black panels varied in total appearance, i.e., colorimetric attributes, specular gloss, and distinctness of image as well as the orange peel. Since many appearance parameters affect the color perception of effect coatings, it was decided to select metallic black panels with approximately the same appearance. First, 20 metallic black panels with the highest DOI and specular gloss as well as the lowest OP parameters were selected from the 70 prepared panels. While the 20 selected panels benefitted from approximately the same specular gloss, DOI and OP, they varied in colorimetric attributes, i.e., lightness, chroma and hue. To restrict the potential effect of colorimetric properties on blackness perception,[16–22] it was decided to select metallic black panels with nearly the same chroma and hue. Regarding the hue preference of observers in blackness perception,[16,17,21,22] metallic black panels with cyanish to bluish tint effects were separated. By considering the adjacency of samples to the lightness axis, finally 6 metallic black panels which just differed on their L^* values were selected from the 20 black panels. So, it seems that lightness is the only colorimetric attribute which affects the blackness perception of metallic black panels.

Instrumental measurements

Because of the ability of goniophotometers to measure the surface reflection profile, the Novo-Gloss I.Q. Goniophotometer from Rhopoint Instruments (UK) was used to determine the distinctness of the images (DOI) as well as the specular gloss values of the paint panels at 20° measuring geometry. Additionally, a BYK-Gardner Wave scan DOI (BYK-Gardner, Germany) was used to evaluate the waviness of the paint panels in terms of orange peel parameters, i.e., Wa, Wb, Wc, Wd, We, Lw and Sw.

The goniospectrophotometer Color Eye 741 GL from Gretag Macbeth was used to determine the colorimetric attributes of the metallic black panels at aspecular angles of 20°, 45°, 75° and 110° under D65 standard illuminant. Samples were measured three times over the visible wavelengths from 360 to 750 nm by 10-nm intervals, while the UV content was included and the aperture size was 16 mm. Regarding the narrow range of lightness variation achieved under 45°, 75° and 110°, it was reasonably preferred to report the colorimetric attributes at the aspecular angle of 20° to decrease the measurement error of the device.

Visual assessment experiments

Illumination setup

In order to investigate the effect of the type of illumination on blackness perception of the metallic black panels, three different setups including diffuse illumination, unidirectional illumination and the light booth were considered.

Under the diffuse illumination which simulates the illumination conditions on a cloudy day, samples were illuminated diffusely and uniformly. To prepare this setup, fluorescent lamps with the illuminance level of 2100 lux and a correlated color temperature of 6150 K were applied[4] in a room with white walls.

Under the unidirectional illumination, the lightening conditions of a sunny day was simulated where samples were illuminated with a series of parallel lights. In the present work, the illuminance level of about 10,000 lux with the correlated color temperature of 5600 K[4] was applied to evaluate the samples.

The VeriVide light booth (Model: CAC 120) was considered as the third setup for evaluating the blackness of the metallic black panels while a fluorescent daylight simulator simulated the D65 standard illuminant as the light source.

Observers

Fourteen non-expert observers (5 males and 9 females) assessed the samples under the three employed illumination setups. The Ishihara test was applied to examine the normal color vision of the observers. A rotation table was used under the three illumination conditions to present the viewing condition of 45/0 (illumination/observation). The mentioned geometry was applied to decrease the effect of gloss on the blackness perception. Observers evaluated the samples from a distance of about 40 cm; they were already familiar with the concept of blackness. In order to rank the perceived blackness of the six metallic black panels, the pair comparison method[23–26] was applied for the visual assessment experiments. According to this method, the number of pairs for n specimens is equal to $n(n-1)/2$.[25,26] Thus, for six metallic black panels, there are 15 panel pairs which observers should separately evaluate under each illumination condition. In this way, for three types of illumination, a total of 45 pair comparisons have been carried out by each observer where each panel pair was randomly presented to the observers to evaluate which panel is the blacker one. The observers used cotton gloves to prevent directly touching the samples.

Observers' accuracy

The intra-observer (repeatability) and the inter-observer (reproducibility) agreements in the blackness perception of the metallic black panels were controlled based on the wrong decision criterion (WDC).[15] According to this criterion, the disagreements between the results represented by an individual observer in repeated visual assessment experiments are considered as wrong decisions. Thus, the smaller the percentages of WDs, the greater the intra-observer agreement (repeatability). For reproducibility, the wrong decisions are defined as the disagreements between the results represented by an individual observer and those assigned to metallic black panels by all the observers (visual scales). For example, if the assigned visual scale of sample A was greater than sample B, it means that observers on average assessed sample A to be blacker than sample B. So, if an observer evaluates sample B to be blacker than sample A, a wrong decision is recorded for him/her. Again, the smaller the percentages of wrong decisions, the greater the inter-observer agreement (reproducibility).

Results and discussion

Figure 1 shows the three-dimensional plot of appearance factors of the metallic black panels. The x, y and z axes show the LW as the orange peel parameter, the distinctness of image and the specular gloss, respectively. According to Fig. 1, the 70 prepared panels vary in appearance parameters while the 20 selected panels have approximately the same specular gloss, DOI and

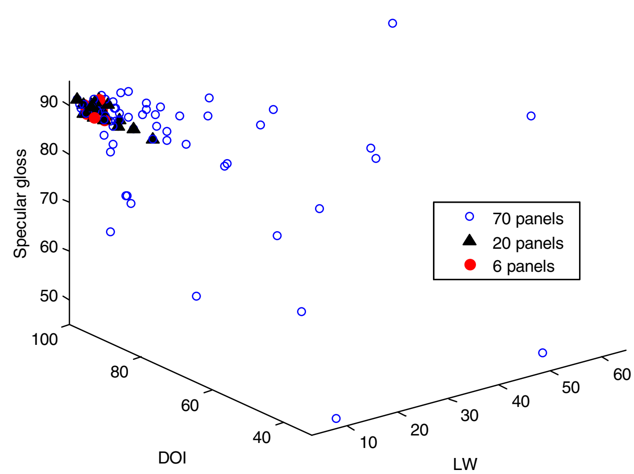

Fig. 1: A three-dimensional scatter plot of instrumentally measured appearance factors of the metallic black panels

OP. On the other hand, the specular gloss of the 6 selected panels varies between 86.40 and 90.60 GU and their DOI attribute is in the range of 97.13–98.5. In addition, the LW factor of the 6 selected panels varies between 4.7 and 8.

The a^*b^* as well as the C^*L^* scatter plots of the paint panels over the CIELAB and CIELCH color spaces are shown in Figs. 2 and 3, respectively.

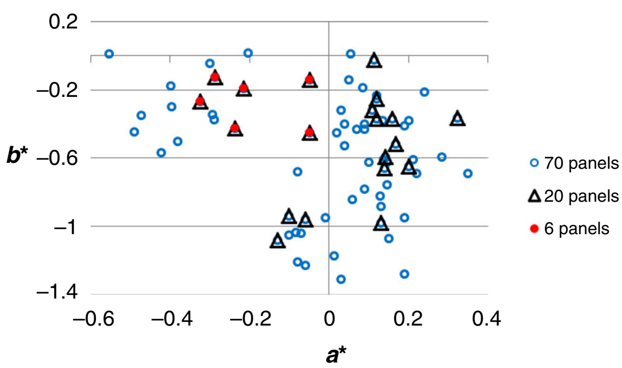

Fig. 2: The a^*b^* scatter plot of the metallic black panels over the CIELAB color space

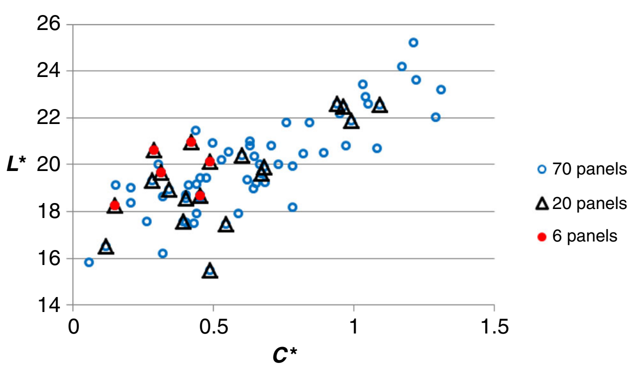

Fig. 3: The C^*L^* scatter plot of the metallic black panels over the CIELCH color space

Figure 2 shows that all the 6 selected panels are located in the third quarter of the hue area, i.e., 180°–270°, and benefit from a cyanish to bluish tint effect. According to Fig. 3, the lightness values of the 6 selected samples (L^*) vary from 18.26 to 20.98. In addition, the small chroma values (C^*) of the 6 selected metallic black panels (0.15–0.49) indicate the closeness of the black panels to the lightness axis.

As mentioned before, the visual assessments were carried out by employing the pair comparison method. The results of the visual assessment experiments were analyzed based on Thurstone's law of comparative judgments[25] and represented as visual scales. Table 1 shows the results of the visual assessment experiments under different types of illumination as well as the colorimetric attributes of the metallic black panels. It is noticeable that the visual scales indicate the average perceived blackness of observers where the higher scale value means the higher degree of blackness perceived by the observers. In addition, based on the law of comparative judgments, the Thurstone zero value is an arbitrary zero[25] and assigned to a panel which observers judged on average to have the lowest degree of blackness. Since the scale values achieved from the three illumination conditions are relative values, just their ranking can be compared across different illuminations.

The reliability of the visual assessments was examined based on the percentage of wrong decisions (WD%) of observers in repeated experiments (repeatability) and on the concept of inter-observer agreement (reproducibility). Table 2 shows the intra-observer as well as the inter-observer agreements in terms of minimum, mean and maximum values of the wrong decisions' percentages. According to Table 2, by repeating the visual assessment experiments, observers evaluated the blackness of the metallic black panels under the light booth and diffuse illumination conditions with minimum and maximum errors of 6.7% and 53.3%, respectively. For the unidirectional illumination, the minimum error of repeatability increased to 13.3% while the maximum one decreased to 46.7%. In addition, the minimum and maximum errors of inter-

Table 1: The colorimetric attributes as well as the visual scales of metallic black panels under different illumination conditions

Sample	Colorimetric attributes					Visual scales[a]		
	L^*	a^*	b^*	C^*	$h°$	Light booth	Diffuse illumination	Unidirectional illumination
B12	20.13	−0.24	−0.43	0.49	241.04	0	0.48	0.36
B6	19.67	−0.29	−0.12	0.31	203.38	0.86	0.79	0.33
B10	18.70	−0.05	−0.45	0.45	263.73	1.31	1.12	0.40
B15	20.62	−0.21	−0.19	0.29	222.05	1.30	0.44	0
B9	18.26	−0.05	−0.14	0.15	250.79	2.38	2.13	1.21
B16	20.98	−0.32	−0.27	0.42	219.62	0.87	0	0.06

[a] Visual scales are relative values and cannot be compared directly across the three illumination conditions

observer agreement to assess the blackness of the metallic black panels under the light booth were, respectively, 6.67% and 40%. These values increased when panels were assessed under the diffuse illumination condition and the unidirectional illumination. However, it was found that the percentages of errors achieved for the repeatability and reproducibility of the visual scales in the current work are in agreement with those reported in other sources.[15,16]

Table 2: The intra-observer (repeatability) and inter-observer (reproducibility) agreements based on the wrong decision criterion

Illumination setup	Repeatability (WD %)			Reproducibility (WD %)		
	Min	Mean	Max	Min	Mean	Max
Light booth	6.7	24.45	53.3	6.67	22.86	40
Diffuse illumination	6.7	34.45	53.3	13.33	25.71	46.67
Unidirectional illumination	13.3	33.32	46.7	13.33	34.76	60

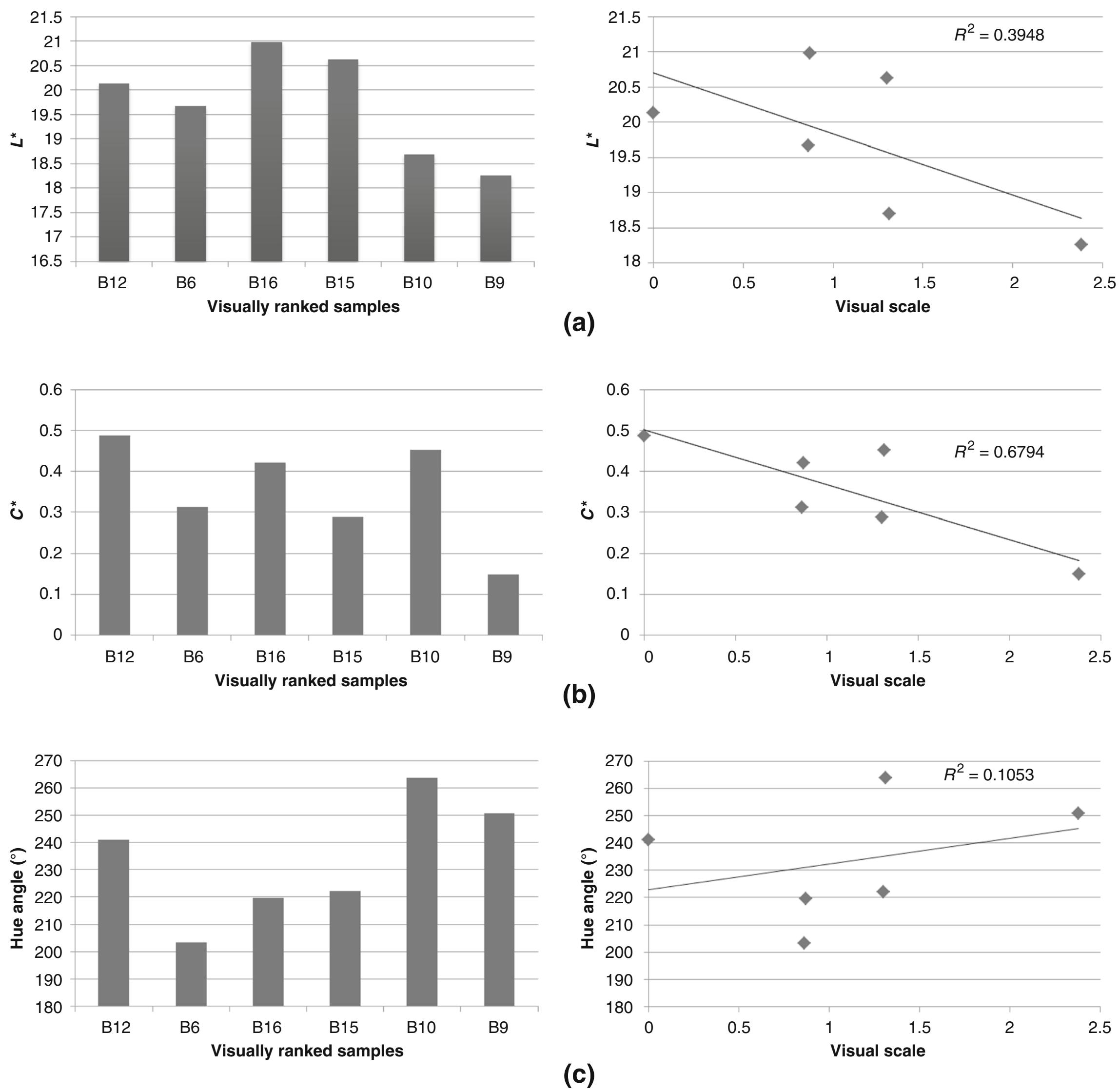

Fig. 4: The (a) lightness, (b) chroma and (c) hue attributes of the metallic black panels visually ranked under the light booth. The *x* axes show the panels' name and their visual scales while the perceived blackness increases from left to right

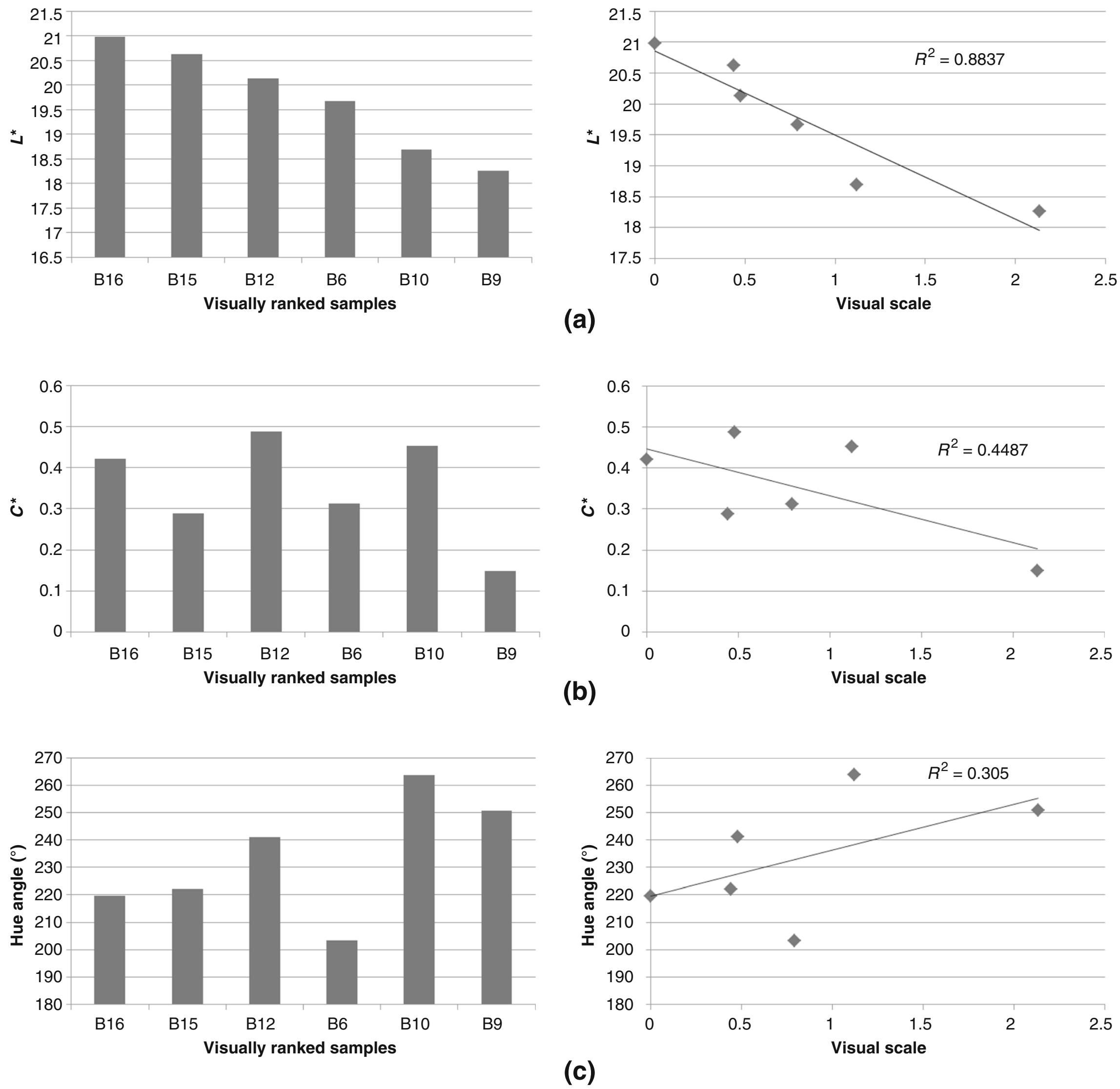

Fig. 5: The (a) lightness, (b) chroma and (c) hue attributes of the metallic black panels visually ranked under the diffuse illumination condition. The *x* axes show the panels' name and their visual scales while the perceived blackness increases from left to right

Figures 4, 5 and 6 show the colorimetric attributes of the visually ranked samples evaluated under the light booth, diffuse and unidirectional illumination conditions, respectively. The (a)–(c) plots of these figures indicate the lightness and chroma as well as the hue attributes of the metallic black panels based on the order of their perceived blackness. The horizontal axes in the lefthand plots show the panels' name where their perceived blackness increases from left to right. In the righthand plots, the *x* axes represent the visual scales of the samples while the higher scale values indicate on average the greater perceived blackness. In addition, the coefficients of determination (R^2) between the colorimetric attributes and the visual scales are shown in the righthand plots.

Figure 4 shows that there is no significant relationship between the perceived blackness of the metallic black panels and their corresponding colorimetric attributes under the light booth. For example, samples B16 and B15, with, respectively, the L^* values of 20.98 and 20.62, benefit from the higher lightness values rather than the other panels. So, it is expected that the observers assess these two lighter panels with the minimal degrees of blackness while they have been located in the middle part of the plots. The coefficients of determination resulted from the lightness ($R^2 = 0.39$), chroma ($R^2 = 0.68$) and hue ($R^2 = 0.11$) attributes with visual scales show that there is not a strong correlation between the panels' colorimetric attributes and their perceived blackness under the light booth. Based on the achieved percentage of wrong decisions, under the light booth the metallic black panels were assessed more precisely than either the diffuse or the unidirectional illuminations (Table 2).

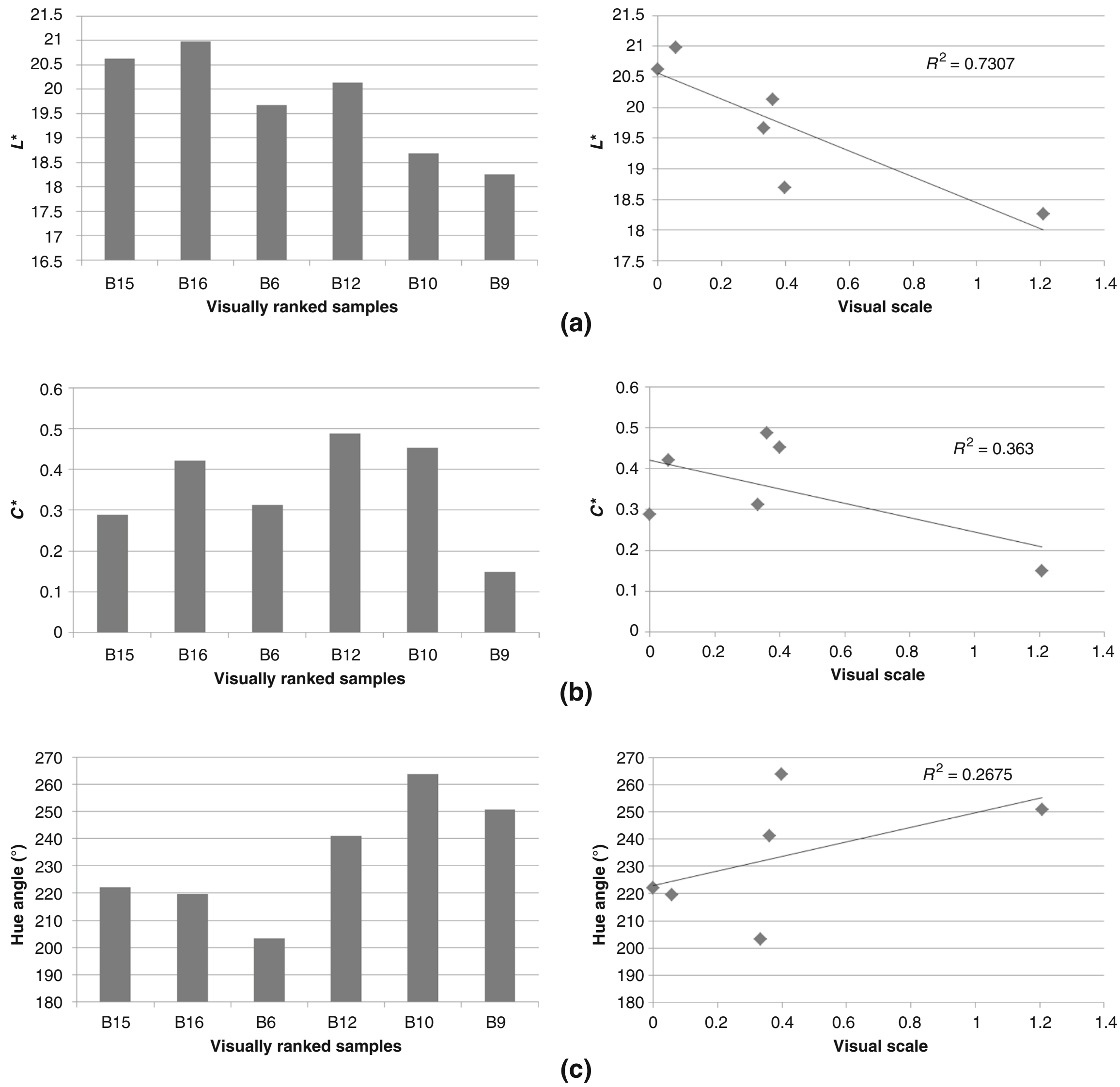

Fig. 6: The (a) lightness, (b) chroma and (c) hue attributes of the metallic black panels visually ranked under the unidirectional illumination condition. The *x* axes show the panels' name and their visual scales while the perceived blackness increases from left to right

Figure 5 shows the variation of the colorimetric properties of the metallic black panels visually ranked under the diffuse illumination condition. According to Fig. 5a, a logical trend is observed between the lightness attribute of the metallic black panels and their blackness perception. In fact, based on Fig. 5a, as the perceived blackness of panels increased their corresponding L^* values decreased. The good coefficient of determination ($R^2 = 0.88$) achieved between the visual scales and the lightness attribute of the metallic black panels proves this claim. Regarding the limited range of the lightness attribute (18.26–20.98) of the 6 metallic black panels and the small variation between their L^* values (Fig. 5a; Table 1), it was found that, among the 15 evaluated pairs, there are some pair panels which their L^* values differ by only a 0.5 step or even less. Thus, detecting the small variation of the lightness attribute of the panels and ranking them just based on their L^* values is noticeable. On the other hand, it seems that, under the diffuse illumination condition, the first assumption of the authors based on the similarity of the samples in the chroma and hue attributes is proved. The observers assessed the blackness of the panels based only on their lightness, and the coefficients of determination between the chroma and visual scales ($R^2 = 0.45$) as well as between hue and visual scales ($R^2 = 0.30$) are not significant.

The colorimetric attributes of the 6 metallic black panels visually ranked under the unidirectional illumination condition are shown in Fig. 6. Similar to the light booth (Fig. 4), no strong correlation is observed between the colorimetric attributes of the metallic black panels and their corresponding visual scales when the panels were evaluated under the unidirectional illumination. The low coefficients of determination resulting from the lightness ($R^2 = 0.73$), chroma ($R^2 = 0.36$) and hue ($R^2 = 0.27$) attributes with the visual scales prove this. In other words, under the unidirectional illumination, the increase of perceived blackness of the metallic black panels does not conform to certain increases or decreases in their corresponding colorimetric attributes (L^*, C^* and hue angle).

Regarding the small range of variation in the L^* values of the black panels (Table 1), it was interesting that the small differences in the lightness attribute were detectable by the observers under the diffuse illumination condition (Fig. 5). This outcome was not repeated for the visual experiments carried out under the light booth (Fig. 4) and the unidirectional illumination (Fig. 6). However, this may be due to the small number of black panels used in the visual evaluation tests.

Comparing Figs. 5 and 6, indicates that there are some similarities in the blackness perception of the metallic black panels under the diffuse illumination condition and the unidirectional one. According to these figures, while there are some disagreements in the evaluation of the blackness of the panels, certain couples of samples, i.e., B16 and B15, B12 and B6, and B10 and B9, have been assessed with specific ranking positions. For instance, under the diffuse illumination condition, samples B16 and B15 with, respectively, the visual scales of 0 and 0.44 were assessed as the least blacks among all the metallic black panels (Fig. 5; Table 1). Under the unidirectional illumination, just the order of the mentioned panels is changed, and again samples B15 and B16 with the visual scales of 0 and 0.06 are assessed as the pair with the minimum degree of blackness (Fig. 6; Table 1). This case is again observed for the pair panels of B12 and B6. The uncertainty of the observers in making the same decision for ranking the panels of a certain pair under two different illumination conditions may refer to the high similarities between the panels' colorimetric and appearance attributes.

On the other hand, regarding Figs. 4, 5 and 6, it is observed that samples B10 and B9 with the certain order were constantly perceived as the blacker panels under three different illumination conditions. The plots of Figs. 4a, 5a and 6a as well as Table 1 indicate the lower lightness values of these panels ($L^*_{B10} = 18.70$ and $L^*_{B9} = 18.26$) rather than all the samples. In other words, among the 6 selected metallic black panels with nearly the same hue and chroma values, the observers constantly assessed the darker ones as the blacker panels under different lighting conditions. In addition, according to Table 1 and Figs. 4, 5 and 6, sample B9 with the lowest lightness and chroma values ($L^*_{B9} = 18.26$, $C^*_{B9} = 0.15$) was always perceived with the highest degree of blackness. It means that, as expected, the observers judged the darkest and the most neutral panel as the blackest metallic panel under the three different illumination conditions.

Conclusion

The effect of different types of illumination on the blackness perception of automotive finishes was investigated by utilizing visual assessment experiments under three different illuminating setups, i.e., unidirectional illumination, diffuse illumination and the light booth. To restrict the parameters which affect the blackness perception, it was decided to select metallic black panels with approximately the same colorimetric and appearance attributes. The pair comparison method was applied to visually rank the blackness perception of the 6 selected metallic black panels. The observers' accuracy was examined based on the wrong decision criterion in terms of intra-observer agreement (repeatability) and inter-observer agreement (reproducibility). The results showed that both the repeatability and reproducibility of the visual scales were acceptable. From the results, it is suggested that, under the diffuse illumination condition, the pair compared metallic black panels could be visually ranked based on their lightness. So, the poor correlation achieved between the perceived blackness of the metallic black panels and their corresponding colorimetric attributes (lightness, chroma and hue) under the unidirectional illumination and the light booth may refer to the small number of samples used in the visual assessment experiments. Moreover, irrespective of certain dissimilarities between the ranks assigned to the black panels under different illuminating conditions, the observers constantly assessed the darkest and the most neutral black panel as the blackest metallic panel.

References

1. Hutchings, JB, *Food Colour and Appearance*. Blackie, London (1994)
2. Dekker, N, Kirchner, E, Super, R, van den Kieboom, GJ, Gottenbos, R, "Total Appearance Differences for Metallic and Pearlescent Materials: Contributions from Color and Texture." *Color Res. Appl.*, **36** 4–14 (2011)
3. Hutchings, J, "The Continuity of Colour, Design, Art And Science. I. The Philosophy of the Total Appearance Concept and Image Measurement." *Color Res. Appl.*, **20** 296–306 (1995)
4. Hutchings, J, "The Continuity of Colour, Design, Art and Science. II. Application of the Total Appearance Concept to Image Creation." *Color Res. Appl.*, **20** 307–312 (1995)
5. Mirjalili, F, Moradian, S, Ameri, F, "A New Approach to Investigate Relationships Between Certain Instrumentally Measured Appearance Parameters and Their Visually Perceived Equivalents in the Automotive Industry." *J. Coat. Technol. Res.*, **11** 341–350 (2014)
6. Streitberger, HJ, Dossel, KF, *Automotive Paints and Coatings*. WILEY-VCH, Weinheim (2008)

7. Ameri, F, Khalili, N, Moradian, S, Zaarei, D, Mirjalili, F, "Correlation Between the BYK's Balance Index and the Appearance of Visually Assessed Achromatic Automotive Finishes." *Prog. Org. Coat.*, **77** 425–430 (2014)
8. Nadal, ME, Thompson, EA, "NIST Reference Goniophotometer for Specular Gloss Measurements." *J. Coat. Technol.*, **73** 73–80 (2001)
9. CIE 175:2006 Report, "A Framework for the Measurement of Visual Appearance." Central Bureau of the International Commission on Illumination, CIE, Paris, 2006.
10. Hunter, RS, Harold, RW, *The Measurement of Appearance*. Wiley, New York (1987)
11. Kirchner, E, van den Kieboom, GJ, Njo, L, Super, R, Gottenbos, R, "Observation of Visual Texture of Metallic and Pearlescent Materials." *Color Res. Appl.*, **32** 256–266 (2007)
12. http://www.ppg.com/en/newsroom/news/Pages/20131024A.aspx, 2015.
13. McDonald, R, *Color Physics for Industry*, 2nd ed. Dyers, Bradford (1997)
14. Jafari, R, Amirshahi, SH, Ravandi, SA, "Spectral Analysis of Blacks." *Color Res. Appl.*, **37** 176–185 (2012)
15. Westland, S, Cheung, TLV, Lozman, OR, "A Metric for Predicting Perceptual Blackness." *Presented at the 14th Color Imaging Conference Final Program and Proceedings*, Society for Imaging Science and Technology, Arizona, pp. 14–17, 2006
16. Clonts, JR, Shamey, R, Hinks, D, "The Effect of Hue on the Perception of Blackness Using Munsell Samples." *Color Res. Appl.*, **38** 423–428 (2013)
17. Clonts, JR, Shamey, R, Hinks, D, "Effect of Colorimetric Attributes on Perceived Blackness of Materials." *Presented at the 4th European Conference on Colour in Graphics, Imaging, and Vision,* Finland, pp. 83–87, 2010
18. Tao, L, "Impact of Blackness Preference and Perception on Product Design," PhD thesis, University of Leeds, England (2013)
19. Tao, L, Westland, S, Cheung, V, "Blackness: Preference and Perception (Hue)." *Presented at the 19th IS&T/SID Color and Imaging Conference*, San Jose, pp. 270–275, 2011
20. Tao, L, Westland, S, Cheung, V, "Blackness: Preference and Perception (Value and Chroma)." *Presented at the 6th European Conference on Colour in Graphics, Imaging, and Vision*, Amsterdam, pp. 253–258, 2012
21. Jafari, R, Amirshahi, SH, Hosseini Ravandi, SA, "Blacks Colorimetric Boundaries Based on the Perceived Blackness," *Presented at the 12th Congress of the International Color Association, AIC Color 2013,* Newcastle, United Kingdom, pp. 503–506, 2013
22. Jafari, R, Amirshahi, SH, Hosseini Ravandi, SA, "Effect of Lightness on Blackness Preference of Black Fabrics." *Prog. Color Colorants Coat.*, **8** 11–24 (2015)
23. Torgerson, WS, *Theory and Methods of Scaling*. Wiley, New York (1958)
24. Fairchild, MD, *Color Appearance Models*. Addision Weseley, Massachusetts (1998)
25. Thurstone, LL, "A Law of Comparative Judgment." *Psychol. Rev.*, **34** 273–286 (1927)
26. Guilford, JP, *Psychometric Methods*. McGraw-Hill, New York (1954)