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Artificial Eye Iris Painting Colour Scale

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Abstract

The purpose of this study was to develop an artificial eye iris-painting colour scale, which can be used as an auxiliary tool for this stage of production. In order to map out the present shades in human irises, seven hues have been developed (Reddish-Brown, Brown, Ochre, Green, Bluish-Green, Blue and Grey) by mixing Acrilex® acrylic paint, which were based on the concepts of iris colour formation for the establishment of the paint mixtures. The scale was tested by three calibrated observers in 145 individuals presenting healthy irises, considering the iris' predominant shade only. The observers would verify if any of the shades in the colour scale matched the subject's iris colour base, without knowing their peers' opinions. Each observer's

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opinion was registered into an iris evaluation sheet and the data was then submitted to statistical analysis. Chi-squared distribution (a = 0.05) revealed no tendency of the observer to choose a specific hue (p = 0.95). Fleiss' kappa assessment pointed out a very high inter-observer coherence in relation to the hue (κ = 0.86). Kendall's W values for each hue were the following: Reddish-Brown (0.607); Brown (0.618); Ochre (0.629); Green (0.76); Bluish-Green (0.821); Grey (0.111). As for the blue hue, however, there wasn't absolute agreement among the observers for any individual; therefore, this hue could not be analysed. The developed scale can be used as a colour guide, so as to facilitate the iris painting process. Even not having the colour scale in hands, the professional can make use of the described paint mixtures.

Keywords: Artificial eye, maxillofacial prosthesis, eye colour, prosthesis colouring, iris

INTRODUCTION

The segment of ocular prosthetic rehabilitation is in constant development in Maxillofacial Prosthetics due to ocular loss progression for pathological and traumatic reasons, caused by aggressions and traffic accidents inherent to modern urban life (Côas, Neves, and Rode 2005).

Artificial eye is a modality of facial prosthesis that aims to alloplastically repair the loss or deformities of the ocular bulb (Cain 1982). The main role of rehabilitation through ocular prosthesis is to minimize functional and aesthetic disorders resulting from the loss, and is furthermore important for proper orbital region bone development in children (Mattos et al. 2006). Its regular use for patients in need of this type of rehabilitation may prevent palpebral collapse and deformation, protect the cavity lining, restore lachrymal direction, and maintain muscle tone, which retains symmetry in the facial contour (Bartlett and Moore 1973; Parr, Goldman, and Rahn 1983; Simões, dos Reis, and Dias 2008; Murphey and Schlossberg 1945).

Patients' psychological distress is very common. Confusion of the individual's identity manifests when losing a portion of the face substance, where the eyes are commonly the most expressive factor

(Bruce 1940). This leads the individual's self-esteem to low levels, hindering interpersonal interactions and thus harming their quality of life. Aesthetic and functional restoration is paramount in order to minimize patients' psychological struggle (Bailey and Edwards 1975; Gillis, Swenson, and Laney 1979; Ahn, Lee, and Yoon 2010; Goiato et al. 2014).

Aesthetic significance and lifetime of the ocular prosthesis have fostered research focusing on the improvement of iris-painting techniques. Over the years, several iris painting methodologies have been proposed, using different kinds of brushes, paints, and painting surfaces (Dietz 1945; Erpf, Wirtz, and Dietz 1946; Brown 1970; Murphey and Schlossberg 1945). Studies evaluated various kinds of paints with respect to their chromatic stability and colour variance under diverse illumination (Benson 1977; Fernandes et al. 2009; Goiato et al. 2010; Bannwart et al. 2013; Mundim et al. 2012).

As this concerns the rehabilitation of a paired organ, ocular prosthesis should generate a faithful copy of the patient's remaining eye, mainly considering the artificial iris painting and diameter for a satisfactory simulation (Carvalho et al. 2008). Iris detail reproduction requires chromatic derivation of the used pigments, often achieved through arbitrary paint mixtures, thus the iris painting stage can take endless work hours. In order to offer a colour guide that facilitates the iris painting process in ocular prosthesis, the present study aimed to propose and validate a colour scale that covers all tones present in the human iris, through the manipulation of acrylic paints and based on the concepts of iris colour formation for the establishment of paint mixtures, so that it can be used as an auxiliary tool. The scale was expected to be validated by running comparison tests between the developed colour scale and healthy irises by more than one observer. The null hypothesis was that the observers would substantially agree in their opinions, ensuring the legitimacy of the scale.

METHODS

Preliminarily, a heavy aluminium customized muffle (Fig. 1) was milled, used as the mold for the proof-bodies, which were made of Clássico® heat-polymerized acrylic resin. This kind of resin is commonly used as painting surface in ocular prosthesis (Fernandes et al. 2009). Proof-body diameter was set at 12mm, human iris average size (Lefohn, Budge, and Shirley 2003; Sturm and Frudakis 2004; Hemalatha, Chander, and Anitha 2018). Each piece obtained through a single curing cycle presented 7 proof-bodies. The scale was divided into 7 hues, each one consisting of 14 shades, thus, 14 acrylic pieces were produced.

The idealized hues were the following: Reddish-Brown (RB), Brown (BR), Ochre (O), Green (G), Bluish-Green (BG), Blue (B) and Grey (GY) (Fig. 2). All hues have got a base tone, which corresponds to the number 1 of each, except for the bluish-green hue, whose base tone corresponds to its number 5. Each base tone has got a paint mixture recipe, based on the concepts of the iris colour formation. Proof-bodies were painted with Acrilex® acrylic paints.

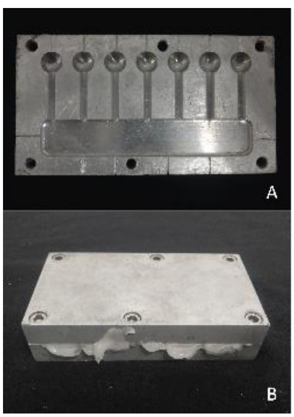

Figure 1 – Heavy aluminium milled plate (A). Closed muffle filled with heat-polymerized acrylic resin (B).

Figure 2 – Developed hues. From top to bottom: Reddish-Brown (RB), Brown (BR), Ochre (O), Green (G), Bluish-Green (BG), Blue (B) and Grey (GY).

Iris colour in humans is determined by the type, amount and distribution of pigments (melanin) in its stroma, as well as by the stroma's cellular density (Sturm and Frudakis 2004; Wang et al. 2005). In the iris stroma, there is a balance of two types of melanin: eumelanin (dark brown to black pigment) and pheomelanin (red to yellow pigment) (Hearing and Tsukamoto 1991; Prota 2000; Prota et al. 1998; Wielgus and Sarna 2005; Wakamatsu et al. 2008). The amount of stromal collagen fibres in the iris defines whether or not the iris will undergo Rayleigh Scattering (Rennie 2012), a non-biological phenomenon responsible for the blue shade illusion in human iris (Lefohn, Budge, and Shirley 2003) by reflecting Tyndall blue when the incident light hits very small particles (Axmann, Bergmann, and Eichberger 2013; Stetefeld, McKenna, and Patel 2016). Low collagen concentration irises are more susceptible to Rayleigh Scattering. This happens because incident light hits these small particles present in the stroma and scatters short wavelengths that reflect a bluish shade; that is to say these irises will have hue variation depending on the offered light. The larger the particles in the iris stroma, the less it will suffer from Rayleigh Scattering, causing lower or insignificant hue variation. Light scattering is not viable in high melanin concentration irises, once incident light is mostly absorbed by large amounts of pigment in the stroma, thus preventing light from passing through the stroma (Wang et al. 2005).

For the establishment of the base tones, paint mixtures simulated amounts of pheomelanin and the levels of Rayleigh Scattering. Black paint stands for eumelanin concentrations, which was gradually folded into the base tones in order to reach darker tones in all hues. Since the Bluish-Green hue base tone corresponded to number 5, titanium white paint was incorporated to the base tone, obtaining the four lighter tones. The spoon-shaped side of a Duflex® Lecron craver nº5 was used as measure for paint proportioning (Murgo and Neves 2001).

Reddish-Brown base tone is purely alizarin crimson paint, representing high pheomelanic concentration irises. Only van dyke brown was used in the Brown hue, which corresponds to average pheomelanic levels, resulting in an orangish shade. Equally proportionate ochre yellow and raw sienna paints composed the Ochre hue, which symbolizes low pheomelanin amounts and the absence of Rayleigh Scattering, as it is yellow-coloured. The Green hue consists of a ten to one ratio of ochre yellow and sap green mixture, simulating low pheomelanin concentration irises, which slightly undergo Rayleigh Scattering. For Bluish-Green and Blue hues, cerulean blue represents considerable levels of Rayleigh Scattering. One cerulean blue part for two parts of ochre yellow, which characterize pheomelanin in low concentrations, resulted in the Bluish-Green base tone. Essentially eumelanic irises are represented by Blue and Grey hues: five titanium white parts combined to one part of cerulean blue for the Blue hue; and equal parts of titanium white and black paints for the Grey hue.

This study was approved by the local research ethics committee under number 1.730.995. The scale was tested by three observers in 145 individuals presenting healthy irises. Observers were previously calibrated. They were instructed not to consider stroma fibres, collarette, limbal ring, or any other anatomical sign, only the iris' predominant shade was taken into account. The observers would verify if any of the shades in the colour scale matched the subject's iris colour base (Fig. 3), not aware of their peers' opinions.

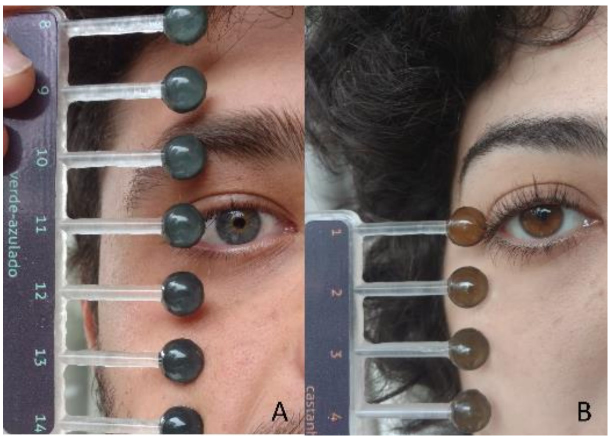

Figure 3 – Human irises matching the Bluish-Green hue (A), and the Brown hue (B).

The subject's eye colour was not a selection criterion, because the intention was o evaluate the iris colour of any random human being. Therefore, more matches for RB and BR were expected, considering that dark brown-coloured irises are genetically dominant in humans (Eiberg 1996) and light-coloured irises are more frequent in the European population (Imesch, Wallow, and Albert 1997). Iris colour check took place under natural light, which is considered a good illumination condition for iris colour observation, always between 9 am and 3 pm, with clear skies, so that the offered illuminant was standardized. Each observer's opinion was registered into an iris evaluation sheet and the data was then submitted to statistical analysis. If the subject's iris colour base didn't match any shade in the scale, then the observer would sign "no colour" in the iris evaluation sheet.

Evaluated factors included the association of the selected hue by the observer (Chi-squared distribution) (α = 0.05); the consistency of the hue choice among all observers (Fleiss' kappa)(Fleiss 1971; Landis and Koch 1977), and the consistency of the choice of shade for each hue (Kendall's W)(Kendall and Smith 1939).

RESULTS

Evaluated irises matches were the following: RB (47,59%); BR (23,91%); O (10,57%); G (6,44%); BG (7,59%); B (1,15%); GY (2,53%); no colour (0,23%).

Hue	Observer 1	Observer 2	Observer 3
Reddish-brown (RB)	70	75	65
Brown (BR)	34	29	38
Ocher (O)	15	15	16
Green (G)	9	9	10
Bluish-green (BG)	11	11	11
Blue (B)	3	1	1
Grey (GY)	3	4	4
No colour	0	1	0

P = 0,95.
Table 1 – Contingency Table (hue x observer)

Association hypothesis between hue selection and observers was tested through a contingency table (Table 1) construction and subsequent Chi-squared distribution application. Significance level of 5% was adopted. Bias existence in hue selection by the observers was assessed; in other words, the tendency of one or more observers to select one or more hues more frequently than expected, in a manner not related to the sample, but the observer. No tendency of the observer to choose a specific hue was observed (p = 0,95).

Agreement between the observers regarding hue selection was determined by Fleiss' kappa. Kappa's resulting value (0,86) pointed out near perfect agreement among observers.

Once having consensus among all observers in relation to the selected hue, agreement among observers considering the selected tone was evaluated. Therefore, Kendall's W analysis with draw correction was applied, aiming to evaluate observers' agreement for ordinal categorical variables. Only samples that presented total consensus among observers were included. Kendall's W values for each hue were tabulated (Table 2).

Hue	Samples included	Kendall's W	Agreement level
Reddish-brown (RB)	62	0,607	High
Brown (BR)	27	0,618	High
Ocher (O)	13	0,629	High
Green (G)	9	0,76	High
Bluish-green (BG)	11	0,821	Very high
Blue (B)	0	-	-
Grey (GY)	2	0,111	Low

Table 2 – Kendall's W assessment.

DISCUSSION

The results of this study don't support the rejection of the null hypothesis, thus the developed colour scale validation has been assured. Firstly, Chi-squared distribution revealed no tendency of the observer to choose a specific hue, ensuring they were properly calibrated. Secondly, Fleiss' kappa analysis was crucial in terms of validation, since it assessed the agreement between the observers regarding the hue selection and showed an almost perfect agreement.

The key point of the whole study was to verify if the evaluated irises matched any of the developed hues, regardless of the selected tone. That is because the difference between the fourteen tones in a hue is basically the amount of black paint (eumelanin), once they derived from a common base tone. Nevertheless, for a deeper analysis, Kendall's coefficient of consensus assessed the agreement among observers considering the selected tone for each hue. Kendall's W values for RB, BR, O, G, and BG indicated a high or very high consensus. GY showed low consensus and B could not be evaluated.

As expected, there were substantially more matches for dark-coloured irises (RB and BR) than for light-coloured irises (Wakamatsu et al. 2008) (O, G, BR, GY, and B). That is because dark brown-coloured irises are genetically dominant in humans (Eiberg 1996) as light-coloured irises are more frequent in the European population, although sporadic occurrence in other populations is noted (Imesch, Wallow, and Albert 1997). This study evaluated irises of Brazilian individuals residing in the state of São Paulo, which may explain the struggle to find light-coloured eyed individuals, especially blue and grey. Thus, there was a diminished sample for GY and B, impairing Kendall's W assessment for these hues. However, if there were more matches, namely a larger sample, the tendency would be to have Kendall's W values nearer to 1, indicating a better consensus. Moreover, all individuals who had at least one match for B scored GY in the rest, suggesting a understated difference between B and GY. Assuming that Rayleigh Scattering is responsible for producing the blue shade in human irises (Lefohn, Budge, and Shirley 2003), that the light scattering varies according to the incident light, and that this phenomenon is only viable in low melanin concentration irises (Wang et al. 2005), the difference between grey and blue irises can be hypothesized. Both colours result from low eumelanin levels in their stroma (Prota et al. 1998; Sturm and Frudakis 2004; Wang et al. 2005; Wakamatsu et al. 2008), so theoretically both would undergo Rayleigh Scattering. However, grey irises may present higher amounts of stromal collagen fibres, making Rayleigh Scattering unviable, once this phenomenon occurs when light hits particles that are smaller than incident wavelength (Axmann, Bergmann, and Eichberger 2013; Stetefeld, McKenna, and Patel 2016). Additionally, grey irises should undergo another type of light scattering: the Mie Scattering. In this case, light hits larger particles and scatters all wavelengths equally, reflecting white or grey (Eiberg 1996). Thus, it may be correct to say that grey irises don't suffer hue variation like blue irises, and there can be some confusion determining whether a blue iris by definition is grey or indeed blue, depending on the light scattering intensity.

The developed colour scale offers a colour guide as a means to facilitate the accurate reproduction of the patient's remaining eye colour in the artificial iris, enhancing the final prosthesis aesthetic, which is paramount in order to minimize patient's psychological damage (Bailey and Edwards 1975; Gillis, Swenson, and Laney 1979; Ahn, Lee, and Yoon 2010; Goiato et al. 2014). Further studies should work toward developing an iris painting methodology using the colour scale, presuming that a highly verisimilar iris painting can be achieved only through the chromatic derivation of the patient's iris predominant colour for detail characterization.

In conclusion, the developed colour scale was validated and can be used as an auxiliary tool in the patient's iris colour determination when painting an artificial iris in ocular prosthesis.

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