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Endpoint criteria for evaluation of image permanence of photographic prints

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Abstract

Light-fading tests were conducted for the several consumer and commercial photographic prints which were available in the current market. The print life of those photographic prints was evaluated subjectively using some sets of endpoint criteria, and also assessed visually by observers. It was confirmed that the evaluation based on the colour difference produced results that correlated well with those of the visual assessment.

Background and purpose

The image permanence of photographic colour prints, such as light fastness [1], gas fastness [2] and thermal/humidity fastness [3], has conventionally been evaluated based on the optical density change in specific colour/density step patches of the prints [4]. Since each R(red), G(green) and B(blue) density change corresponds to the fading of the C(cyan), M(magenta) and Y(yellow) colourants respectively, this density approach is appropriate and convenient for the research and development of photographic prints and their components. On the other hand, this approach has some limitations; for example, the density data cannot be correlated directly with human perception. To resolve this issue, sets of criteria that consider both density changes and density balance, which are related to human perception to some degree for each colour, have been proposed to define the endpoints of photographic prints [5-8].

In contrast, the colour difference approach, which utilises the International Commission on Illumination (CIE) delta E (ΔE) values for the chromaticities of faded and fresh images, can be directly related to human perception. It is also possible to calculate the average of ΔE value for several patches comprising colours with different densities. The colour difference approach and the results were presented at the previous conference NIP31 in 2015 [9]. The study showed that the evaluation based on the colour difference ΔE corresponded well to the visual assessment, while the evaluation based on the density measurements showed some inconsistency to the visual assessment.

However, the evaluation based on the density measurement is still used now. In this study, further pieces of evidences of the validity of the colour difference approach using recent prints of various printing technologies are presented. And the utilisation of the evaluation method is proposed with the appropriate endpoint criteria for the evaluation of image permanence.

Experiments

Print samples

Twelve sample sets of commercially available photographic prints for consumer and commercial use, including dye-based inkjet, pigment-based inkjet, silver halide, electrophotography and D2T2 systems, were prepared. Each sample was named from "S01" to "S12". Two types of the image shown in Figure 1 were included within each sample set. One is comprised of 30 colour patches which are used for optical measurements. It includes several steps of grey, primary colours (C, M and Y), secondary colours (R, G and B) and white (D_{min}). The other is a pictorial image prepared for visual assessments.

Figure 1. *Images for xenon light exposure testing; (left) 30 patches for measurements, (right) Pictorial image for visual assessments*

Xenon light exposure testing

The light-fading tests were conducted for both patch samples and pictorial image samples.

Basically, the test method stipulated in clause 7.2 of ISO 18937; 2014 was applied. The test conditions involved the following: a xenon arc lamp light source with a 373 nm half-cut UV filter and an intensity of 86.5 klx; an atmosphere of 23 °C and 50% RH and a black panel temperature of 35 °C. The total light exposure was 87 Mlx·h.

Measurements

The densities and chromaticities of the patches were determined before and after light exposure. The durations of light exposure were 1, 2, 3, 4, 5 and 6 weeks.

The geometric condition described in ISO 5-4 [10] and the ISO Status A density described in ISO 5-3 [11] were used.

For the chromaticity measurements, the condition M0 described in ISO 13665 [12] was used. The geometry was 45°/0° with a 2° observer for detector and the illuminant was CIE illuminant D50. For each initial and each faded sample after light exposure, the colour differences, ΔE, were calculated. For ΔE, the values CIE 1976 (ΔE^*_{ab}) stipulated in ISO 11664-4 [13] and CIE 2000 ΔE_{00} were both calculated.

Endpoints of fading images

In this study, the five sets of endpoint criteria in Table 1 were applied. The three sets, "Density #A", "Density #B" and "Density #C", are for density approach which has been conventionally used in a photographic area [14][15][16]. The other two sets, "ΔE_{76}" and "ΔE_{76}", are for colour difference approach using an average of each ΔE_{76} and ΔE_{00}. "ΔE_{76}=10" and "ΔE_{00}=5" were proposed as the criteria in the previous study [9].

Visual assessments

The twelve sets of the faded pictorial images were visually assessed by three professional observers, who compared them to the corresponding initial images. The three observers each have over 20 years of experience evaluating photographic images and are familiar with consumer expectations for photographic prints.

Two kinds of visual assessment were conducted. The details of the visual assessment process are as follows.

Visual assessment #1

This assessment decides the rank order among the twelve sets. The same procedure with the previous study [9] was applied.

i) The initial and faded samples (exposed to light for 1, 2, 3, 4, 5 and 6 weeks) were placed next to each other for each sample set, as shown in Figure 13.
ii) Each faded sample was compared to the corresponding initial sample. Larger differences indicated poorer image permanence of the relevant material.
iii) The sets of initial and faded images for each material were the arranged from the best to worst based on the visual assessment, as shown in Figure 13.
iv) Then the fading (image permanence) of each set of two adjacent materials was compared.
v) The degree of fading was rated for each set of two adjacent materials as follows: score 0 for no difference, 1 for a slight difference, 3 for a moderate difference and 9 for a large difference.
vi) Starting from the worst set, which was scored for 0, each sample set was given a score with the summation of the score for difference determined in step v).
vii) The score of each sample set was normalised so that the score of the best sample set would be 100.

Visual assessment #2

For each sample set, this assessment decides an acceptable limit within the series of fading samples. It was intended that the light exposure of the acceptable limit would be compared directly with the light exposure at the endpoint by means of measurements.

i) The initial and faded samples (exposed to light for 1, 2, 3, 4, 5 and 6 weeks) were placed next to each other for each sample set, as shown in Figure 13
ii) Each faded sample was compared to the corresponding initial sample. For each sample set, the observers answered which was the acceptable limit among the faded samples (light exposure duration of 1, 2, 3, 4, 5 and 6 weeks). If the acceptable limit existed between adjacent two samples, they could answer with 0.25 intervals between them.
iii) Each acceptable limit for the light exposure duration (weeks) was converted to the amount of light exposure (Mlx·h).

Results

Density approach

Retention of density was calculated from the measured data for grey, primary colours (C, M and Y) and secondary colours (R, G and B). Besides, a change in colour balance was also calculated for grey and secondary colours (R, G and B). Examples of the results for Sample S03 are shown in Figure 2 and Figure 3. Each of the data series was applied to the criteria in Table 1 and the light exposure at endpoint was determined.

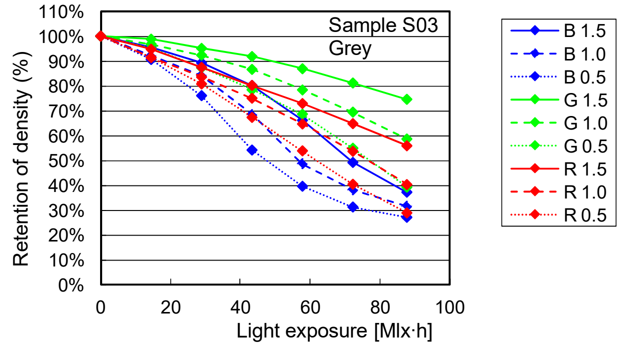

***Figure 2.** Density loss for grey patches of Sample S03*

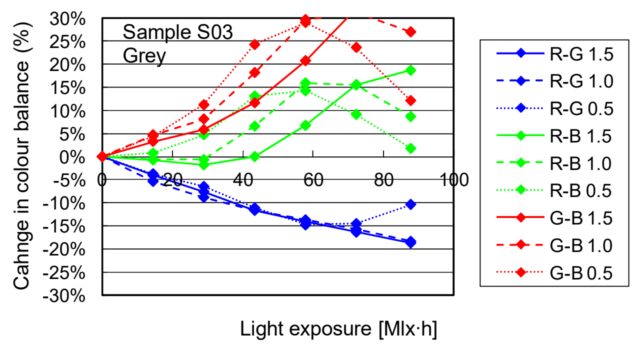

***Figure 3.** Colour balance change for grey patches of Sample S03*

Colour difference approach

The average of each ΔE_{76} and ΔE_{00} was calculated from the colour difference data of all 30 patches. Examples of the results for Sample S03 are shown in Figure 4. Each of data series of ΔE_{76} (average) and ΔE_{00} (average) was applied to the criteria in Table 1 and the light exposure at endpoint was determined.

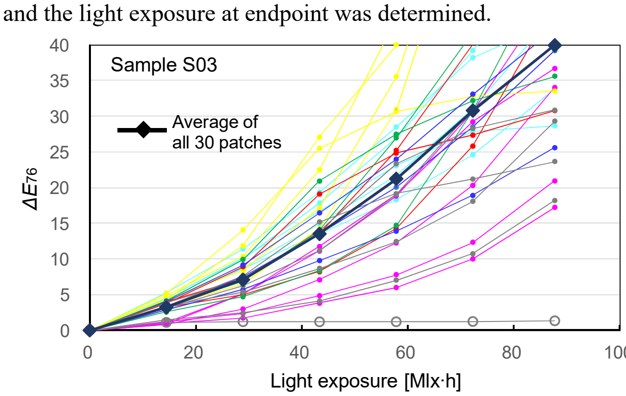

***Figure 4.** ΔE_{76} change for all 30 patches of Sample S03*

Light exposure at the endpoint

Light exposure at endpoint was determined for each four criteria sets listed in Table 1. The results are shown in Figure 5.

There were some significant differences between the three density approaches and the two colour difference approaches.

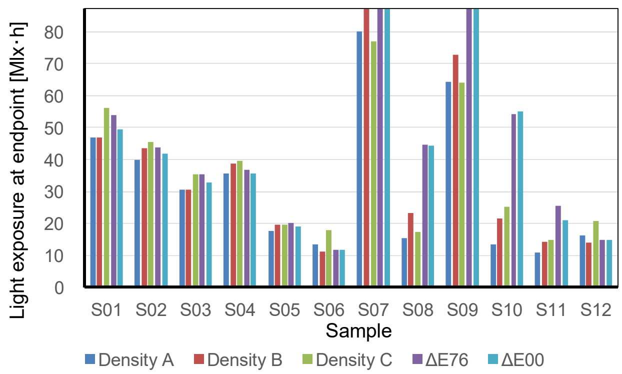

Figure 5. *Light exposure at endpoint for density approaches and colour difference approaches*

Visual assessment

The quantitative results of two visual assessments are shown in Figure 6 and Figure 7. There is no significant difference between the assessments of the three observers.

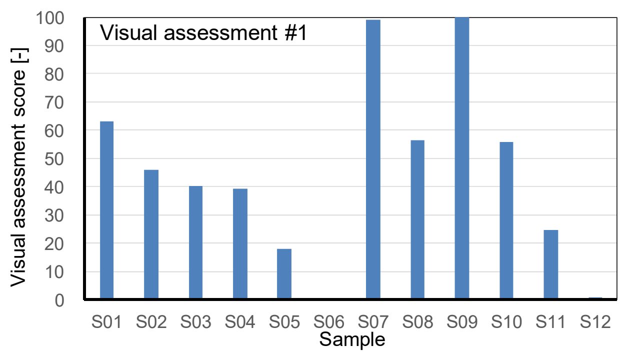

Figure 6. *Results of visual assessment #1*

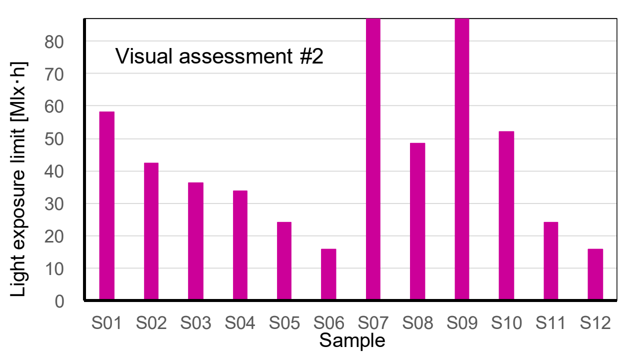

Figure 7. *Results of visual assessment #2*

Visual assessments vs. objective measurements

The correlations between each of the two visual assessments and the light exposure at the endpoint calculated from the density and colour difference data were evaluated.

Visual assessment #1

Correlation data are shown in Figure 8. The X axis represents the light exposure required to reach the endpoint of the four approaches in Table 1, (a) Density #A, (b) Density #B, (c) Density #C, (d) Colour difference ΔE_{76} and (e) Colour difference ΔE_{00}. The Y axis represents the visual assessment score by visual assessment #1.

In all the five figures, strong correlations between the visual assessment and objective measurement results are observed. Especially in the two colour difference approaches of (d) and (e), the best correlation is exhibited. For the three density approaches, samples S08 and S10 are out of correlation.

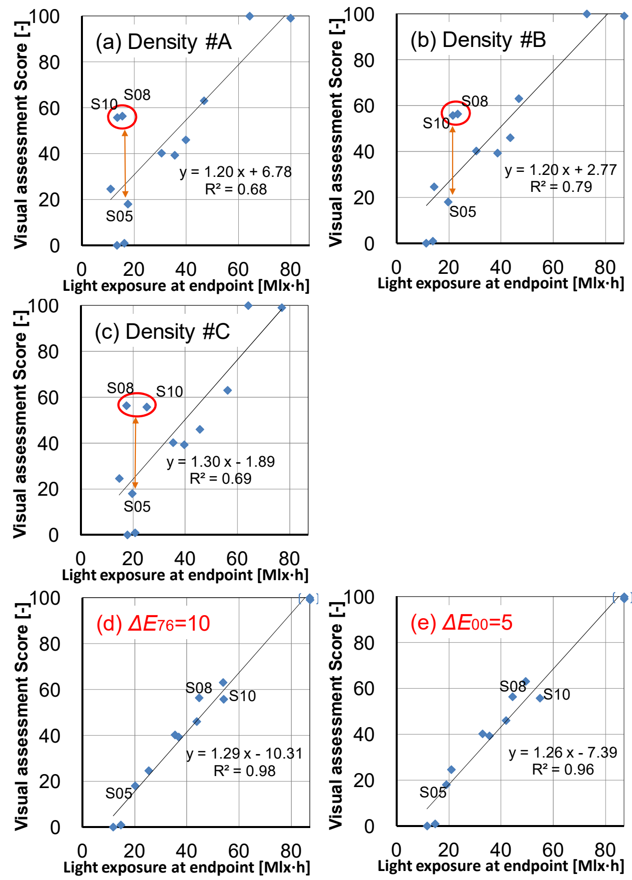

Figure 8. *Visual assessment #1 vs. objective measurements; (a) Density #A, (b) Density #B, (c) Density #C, (d) Colour difference ΔE_{76} and (e) Colour difference ΔE_{00}*

Visual assessment #2

Correlation data are shown in Figure 9. The X axis represents the light exposure required to reach the endpoint of the five approaches in Table 1, (a) Density #A, (b) Density #B, (c) Density #C (d) Colour difference ΔE_{76}, and (e) Colour difference ΔE_{00}. The Y axis represents acceptable limit by visual assessment #2.

As in the case of visual assessment #1, strong correlations between the visual assessment and objective measurement results are observed in all the five figures. Especially in the two colour difference approaches of (d) and (e), the best correlation is exhibited. The light exposure at the endpoint by the two colour difference approaches was extremely close to that of visual assessment.

On the other hand, samples of S08 and S10 were underestimated by the three density approaches compared to visual assessments.

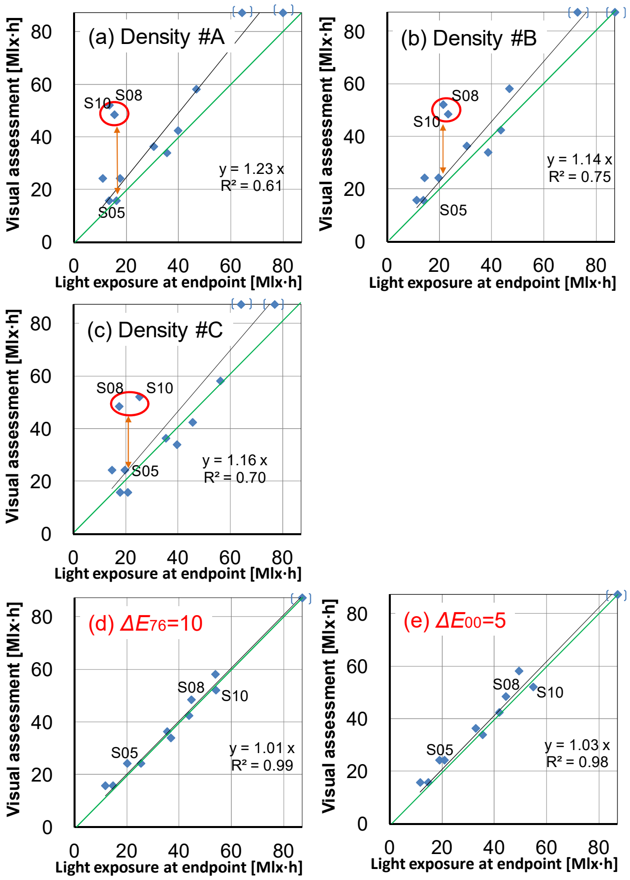

Figure 9. Visual assessment #2 vs. objective measurements; (a) Density #A, (b) Density #B, (c) Density #C, (d) Colour difference ΔE_{76} and (e) Colour difference ΔE_{00}

Consideration

The reasons for the above misfits by density assessments were considered. Figure 10 and Figure 11 show the data of the two significant samples, S08 and S10. Figure 12 shows the data of sample S05, which is almost the same as samples S08 and S10 by the density approaches but poorer than samples S08 and S10 by visual assessment.

Samples S08 and S10 are characterised in that the density change is generally slow, but the density changes is observed by a specific colour for S10, or the density change is hardly observed by a specific colour for S08. As results, colour balance between specific colours changes relatively quickly and reaches the endpoint in a short duration. On the other hand, the density change of S05 is fast for all colours, and colour balance also changes fast accordingly. As results, both density and colour balance changes reach the endpoint in almost the same and short duration.

In S08 and S10, overall fading is not significant except for a patch or a few ones which met the endpoint criteria, and that would be the reason for the misfits.

For the colour difference approach, the misfits are smaller because the average results of all patches were used and because the human perception was taken into account more appropriately.

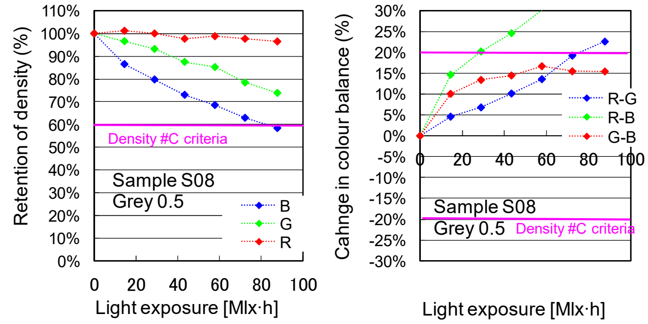

Figure 10. Data of Sample S08 which is underestimated by density approach

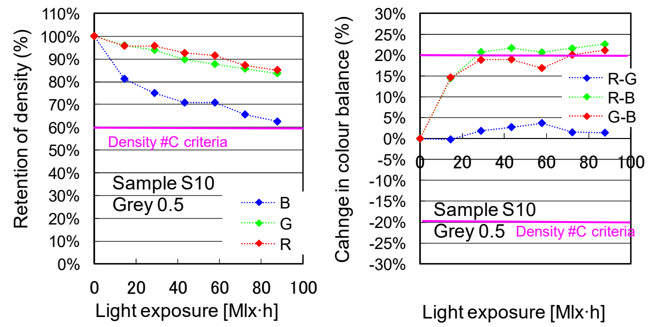

Figure 11. Data of Sample S10 which is underestimated by density approach

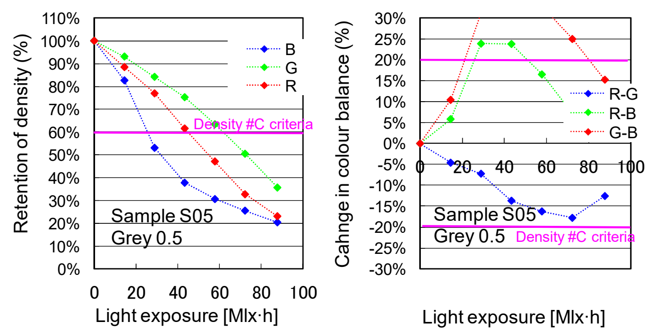

Figure 12. Data of Sample S05 which is equally estimated by both density and colour difference approaches

Conclusion

The validity of the colour difference approach for evaluation of image permanence of photographic prints was confirmed based on the subjective and objective evaluation of light fading of the current consumer and commercial photographic prints.

It is recommended that the evaluation based on the colour difference approach and the proposed endpoint criteria ΔE_{76} =10 and ΔE_{00} =5 be used. Among these two approaches ΔE_{76} is easier to be applied because it requires only simple calculation and has enough validity for evaluation.

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Author Biography

Hiroshi Ishizuka obtained a master's degree in engineering from Tokyo Institute of Technology in 1989. He has worked on development of imaging and display materials in Fujifilm. His work is now focused on international standards for those materials. He is an expert of ISO/TC42 (photography) and IEC /TC110 (electronic display devices).

Evert Groen obtained a bachelor's degree in engineering in 1984 and joined Fujifilm in 1991. He had been involved in research and development of silver halide color photographic film and paper for more than a decade. He was manager of the technical market support and currently business development / key account manager. He is focused on International Standardization by participation as expert.

Nobuhiko Uchino obtained a master's degree in engineering from Japan's Kyushu University in 1985 and subsequently joined Fujifilm. Now, he has focused on International Standardization of digital printing.

Yoshi Shibahara obtained a master's degree in engineering from Japan's Kyoto University in 1978 and subsequently joined Fujifilm. Now, he is an advisory staff of the Fujifilm with the focus on International Standardization of digital printing and electronic displays. He also holds some important positions in the ISO and IEC, such as the Secretary of the IEC/TC 110 (electronic display devices), and the Convenor of ISO/TC 42/WG 3 (image measurement).

Shin Soejima obtained a master's degree from Science University of Tokyo in 1994 and started to work at Fujifilm. He had been involved in research and development of silver halide color photographic paper for a decade. And now, he is a general manager of international standards promotion office in IP headquarter division in Fujifilm.

Wil der Kinderen obtained a bachelor's degree in chemical engineering in 1985 and joined Fujifilm in 1989. First 10 year he was involved in research and development of color forming agents. Next 10 years he was an engineer in the technical market support group. Now he is working for the design and introduction of added value photopapers.

Table 1: LED light source for testing

Category	Item		Patch	Criteria sets for density approach			Criteria for colour difference approach	
				Density #A ref. [14]	Density #B ref. [15]	Density #C ref. [16]	ΔE_{76} ref. [9]	ΔE_{00} ref. [9]
Grey	Density loss	R	Grey	Δ30%	Δ25%	Δ40%	ΔE_{76}=10 for all patches	ΔE_{00}=5 for all patches
		G			Δ20%			
		B			Δ35%			
	Colour balance	R-G	Grey	Δ15%	+12%, -15%	Δ20%		
		R-B			Δ18%			
		G-B			Δ18%			
Primary colour	Density loss	R	C	Δ30%	Δ30%	Δ40%		
		G	M		Δ25%			
		B	Y		Δ35%			
Secondary colour	Density loss	R	G, B	-	-	Δ40%		
		G	R, B		-			
		B	R, G		-			
	Colour balance	R-G	B	-	-	Δ20%		
		R-B	G		-			
		G-B	R		-			
Dmin	Density change	R	Dmin	Δ0.10	Δ0.06	ΔE_{76}=10		
		G			Δ0.06			
		B			Δ0.15			
	Colour balance	R-G	Dmin	Δ0.06	Δ0.05			
		R-B			Δ0.10			
		G-B			Δ0.10			

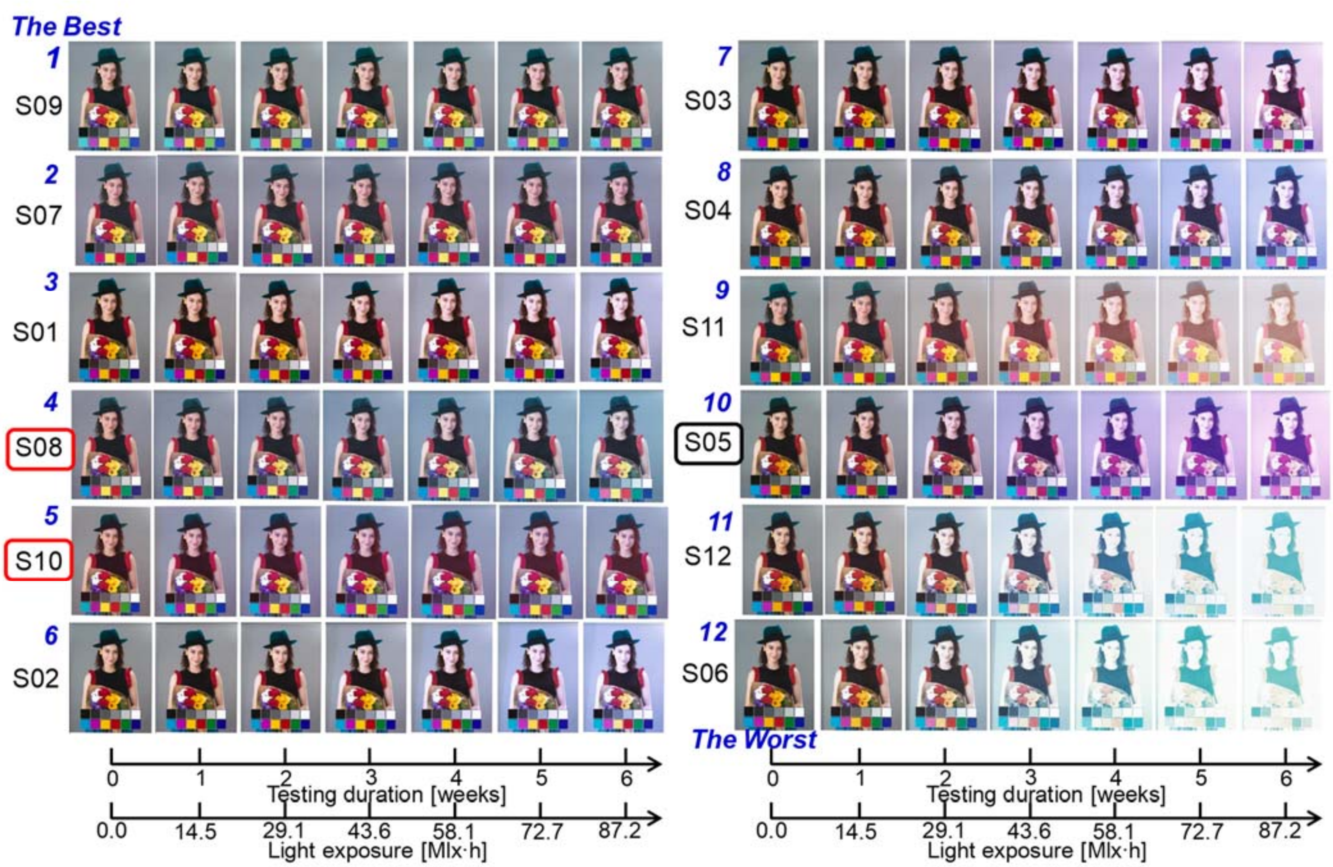

Figure 13. *Results of visual assessment #1*

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