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A study on Memory Colours

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Abstract

Memory colour has generated a sustained interest in the colour world. Previous studies mainly focused on the reflection colour chips and colour samples on real scenes or displays. Less attention was paid to the specific attributes of memory colour. In this paper, the forced choice psychophysical experiment method was used to study the preference, the colourfulness and the naturalness memory colours of 29 familiar objects on mobile displays by Chinese observers. The experiment collected the memory colours data and the representative memory colour was specified by CIELAB L^*, a^*, b^* value. The intra-observer and inter-observer variations were analyzed by mean colour difference from the mean values, which was compared with other similar studies. An ellipsoid model was established to represent results in terms of memory colour centre and colour range in CIELAB a^*b^* space. At the same time, the results of this experiment were compared with those of previous experiments.

Introduction

The term 'memory colour' was used to describe those colours that are recalled in association with familiar objects which we have frequent visual experience. Memory colours were first introduced by Hering [1] in the late 19th century who stated that we view the world through the spectacles of memory. Many scholars support the view that memory colours are considered to be an individual's standard of recollection for familiar objects and the memory colours probably tend to be relatively stabilized. Although memory colours undoubtedly are related to one's particular interests, it seems logical that most people's memory colours for highly familiar objects may be typically more general in their characteristics [2]. It seems apparent that the mean memory colours for the familiar objects examined are not of the same chromaticity as the original object-colour means. Springer [3] designed a study to compare memory colour with colour preference, and to determine whether sophistication about colour technology affects colour memory and preference. Results indicated that, for hue and brightness, memory and preference were quite accurate for the objects tested; however, all subjects remembered and also preferred all items to be more highly saturated. Newhall, Burnham and Clark [4] found that saturation and brightness tended to increase in memory colours and that hue tended to shift towards the dominant hue within the object for some objects. Smet, Ryckaert, Pointer, Deconinck and Hanselaer [5], while investigating colour appearance tolerances for familiar objects, nine familiar real objects were studied. LED lightings were projected to the object to render its colour. Observers were asked to rate the similarity of the perceived object colour to their memory colour. They reported that similarity increases in saturation and shifts towards the dominant hue for most familiar objects. Vurro, Ling and Hurlbert [6] also investigated the memory colour of natural familiar objects. Their primary goal was to compare the memory colour of familiar natural objects by varying natural shape contour, natural chromatic texture, or three-dimensionality, and all combinations of these cues. They found hue shifts in memory colours of natural objects, but these were not systematically towards the dominant hue of the object and also found that hue shifts were reduced by increasing the naturalness of the stimuli. Siple and Springer [3] confirmed the tendency of colour shift not only for saturation increase, but also for good agreement on brightness and hue. In a study by Pérez-Carpinell *et al.*[7] memory saturation only increased for high purity objects, while it decreased or remained the same for mid range or low purity objects. They also reported unsystematic hue shifts specific to the familiar object investigated. There is evidence of an increase of saturation in the memory colours. In most cases there are hue shifts with memory in the direction of what is probably the most impressive chromatic attribute of the object. Memory colour saturation was also higher for the familiar object – a yellow banana – in the study by Yendrikhovskij *et al.* [8]. Memory and preferred colours have also been suggested or used as an internal reference to assess object colour appearance and colour quality in colour reproduction [9-16] and colour rendering [17-20].

Some researchers have studied the culture influence of memory colour. Kevin *et al* [21] investigated the effect of cross-cultural differences on colour appearance ratings and memory colours of familiar objects in seven different countries. They found that the differences between the culture average observers and the global average observer were found to of the same magnitude or smaller than the typical within region inter-observer variability. Bodrogi *et al* [22] established a methodology to study memory colours across different countries and cultures based on homogeneous colour patches. Results indicate that the inter-observer variability in the assessment of the memory colours is strongly context-dependent and twice as large as the inter-group variations. No significant differences in the overall assessment could be found between Chinese and Germans. Zhu *et al* [23] performed a study on long-term memory colours of 26 familiar objects using the asymmetric colour matching method among Chinese and German observers on a display. They found that the cultural effect has a significant impact on the assessment of memory colours when considering specific objects, such as blue sky, nectarine, or broccoli, but has a less significant impact on other colours, like red rose, green apple, and strawberry. Although, there are few studies available to investigate the relationship among colourfulness, preference and naturalness on memory colour perception or colour preference. The goals of this study are to explore the influence of three specific attributes (preference, colourfulness and naturalness) on the colour centre and range of memory colours, and to compare the difference between different studies.

Experiment
Stimuli

The most frequently studied memory colour objects were collected from literature about memory colour. The colour of these objects was converted from different colour spaces to CIELAB colour space [24] under CIE D65 and 1964 standard observer condition. All objects were plotted on CIELAB a^*b^*, a^*L^*, b^*L^* plane respectively. Twenty-nine memory colour objects were selected to ensure that each quadrant of colour coordinate has colour distribution. At the same time, it is necessary to avoid the situation that many objects have very similar colour coordinates. Twenty-nine memory colours including 24 familiar object colours (pork, strawberry, tomato, red rose, carrot, orange, pumpkin, banana, lemon, corn, kiwi, green apple, green pepper, broccoli, grass, pines, smurf, blueberry, blue sky, Pepsi, lavender, purple grape, aubergine and purple cabbage) and 5 Chinese traditional object colours (Chinese festival red, blue and white porcelain, palace red wall, yellow glazed tile and temple yellow wall), which were traditional Chinese colours familiar to Chinese observers.

Fresh and good object samples was prepared. As shows in Figure 1(a), the sample was placed in the centre of the neutral gray light box with a 1000 lux standard D65 light source. The SLR camera was used to take pictures of the experimental samples in manual mode with the exposure time is 1 / 60 second, the aperture value is f / 5.6, the ISO speed is 200, the fixed focal length is 24 mm. The still life image is taken as the initial image of each object. The real surface colour of each sample is obtained by multi-point contact measurement using a spectrophotometer, the spectral reflectance distribution curve of each sample is finally obtained. As shows in Figure 1(b), four models of Caucasian, East Asian, South Asian and African were photographed under a standard D65 light source of 1000 lux. For the objects that are difficult to shoot and measure in the indoor shooting environment with fixed light (such as grass, pine, Smurf, blue sky) and the objects that are difficult to buy suitable samples in the current season (such as roses, lavender, pumpkin), images with a prominent subject, simple background, beautiful shape, natural colour were selected as the initial image of the object. As shows in Figure 1(c), the light environment presented in the selected image should be close to CIE D65 standard light source.

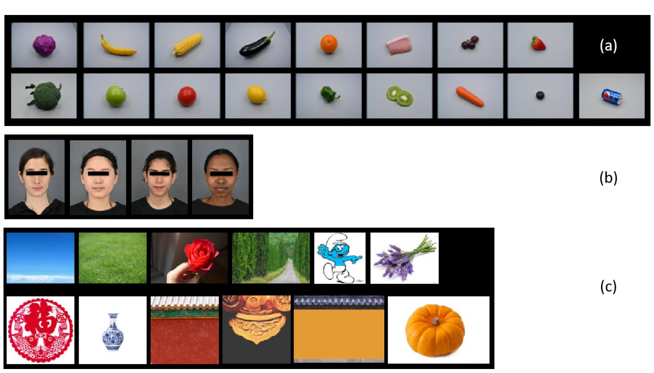
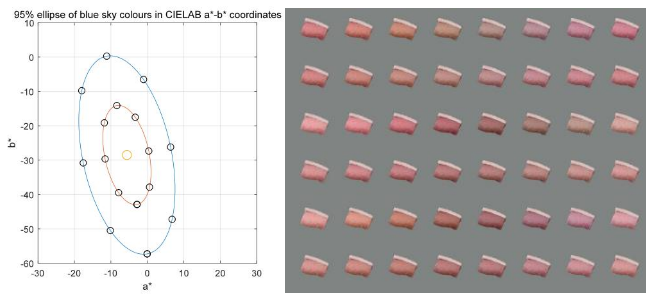


***Figure 1**. Images stimuli used in the experiment, (a) captured objects images, (b)captured skin images, (c) images selected from the internet.*

Image rendering

The captured original images were first masked and then adjusted from the original mean colour into 49 colour coordinates nearby in CIELAB colour space respectively. As shows in Figure 2(a), according to the ellipse range and coordinate axis rotation data of memory color in previous literature [22-23], colour coordinates were selected on the two layers of ellipses with the same centre on the a^*b^*, a^*L^*, b^*L^* planes of CIELAB colour space. The long axis of the outer ellipse is twice that of the inner ellipse. There are points every 45° on each ellipse in each plane. In addition, the initial image is regarded as the origin, and a total of 49 points with different $L^*a^*b^*$ colour coordinates(8 points × 2 ellipses×3 planes+1 origin=49). The 49 coordinate points varied in a certain range in the direction of lightness, chroma and hue angle. Finally, 49 similar images were obtained from each initial image as shows in Figure 2(b).



(a) (b)

***Figure 2**. (a) selection of the image rendering point, (b) image rendering effect of 'pork'.*

Display model

Images were displayed respectively on five 6.1-inch Huawei P20 Pro organic lighting-emitting diode screens. The screen had a native resolution of 2240 × 1080 and a large colour gamut. All monitors were adjusted to achieve a peak luminance of 400 cd/m^2 and a white point at 6500K in CCT using a Spectro-Radiometer Specbos 1211. The auto- brightness function of the smart phones was turned off. The 3D LUT method was used to characterize each display, including 729 colours (9 × 9 × 9) to build the 3D-Look-Up-Table (*3D-LUT*) display model [26]. The five mobile phones were measured 0 degrees perpendicular to the display plane at a distance of 30 cm in the dark condition. The mean colour differences of each smartphone between the predicted and measured results were 1.51, 1.76, 1.37, 1.24 and 1.79, respectively. The mean colour difference between before and after working continuously for an hour of the 5 mobile phones was 0.28. The measurement of the same 24 colour patches was repeated at 24 hours intervals, the average colour difference was 0.36. This means these five displays have good device self-stability. Further investigation was conducted to compare the inter-display agreement, the mean colour difference between each smartphone and the others four smartphones was about 1.9. This means that the predictive accuracy from the *3D-LUT* model was almost the same as the inter-display discrepancy between different displays, indicating the good agreement between the 5 mobile phones used.

Observers and procedure

Thirty Chinese observers participated in the experiment. They were all the students from Zhejiang University. There were 14 female and 16 male observers with a mean age of 22 ranged from 18 to 27 years old. All observers passed the Ishihara colour vision test [26] and had a normal colour vision.

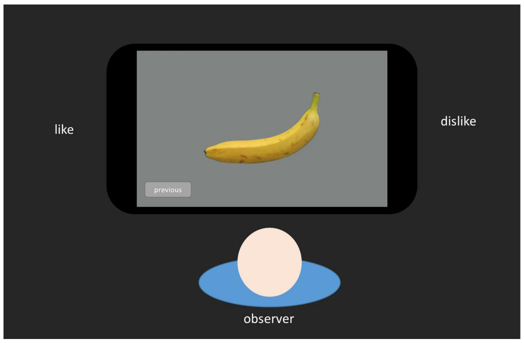


Figure 3. *Experimental situation.*

Figure 3 shows the experimental environment. Observers were asked to sit around a table which was covered by a grey cloth in a dark room. They sit in front of a smartphone at a distance of 40 cm to perform experiment. The image was displayed in landscape mode on the phone. The alternative forced choice method was used. The method was chosen because of its reliability and simplicity. Three attributes of the memory colour in the image were assessed (either 'like' or 'dislike', either 'colourful' or 'not colourful' and either 'natural' or 'unnatural'), one at a time. The order of colours and objects presented on screen were randomly arranged.. In total, 154,350 judgments were obtained in the experiment: 35 (29 images + 6 repeats) × 49 (rendering)×3 (attributes)×30 (observers). The order of stimuli was randomized. The whole experiment lasted for approximately 180 minutes for each observer. They were asked to finish the experiment in three one-hour sessions..

Results and discussion

The results were reported in the form of binary choices. They were arranged in the form of preferred rate *Y%*, which was calculated by the number of the yes decisions divided by the total number of observers multiplying by 100.

Observer variations

The mean-colour-difference from-mean (MCDM) was used in this experiment to assess the observer variability between two sets of visual results. The MCDM value measures the colour variation through colour difference in CIELAB colour space in such a way that a smaller value corresponds to better repeatability, as shows in Equation (1).

$$\mathbf{MCDM} = \frac{1}{N}\sum_{i=1}^{N}\sqrt{(L_i^* - L_i^{*'})^2 + (a_i^* - a_i^{*'})^2 + (b_i^* - b_i^{*'})^2} \qquad (1)$$

In Equation (1), N is the number of the image numbers, $L_i^{*'}$, $a_i^{*'}$, $b_i^{*'}$ are average results of all observers in the calculation of inter-observer variation but are repeated trials of a given observer in the calculation of intra-observer variation. Finally, the average inter-observer and intra-observer variability of the whole panel of observers was obtained by calculating the mean value of all memory colour images in terms of memory colour attribute.

Table 1. Observer variations in MCDM

Inter	*Colourfulness*	*Naturalness*	*Preference*	*Mean*
max	5.6	8.2	6.3	6.7
min	2.3	2.0	0.6	2.4
mean	3.4	3.7	3.8	3.7
Intra	***Colourfulness***	***Naturalness***	***Preference***	***Mean***
max	2.4	2.8	2.6	2.7
min	1.2	1.5	1.2	1.6
mean	1.9	2.1	2.1	2.1

The average inter-observer variability of colourfulness, naturalness and preference were 3.4 ΔE^*_{ab}, 3.7 ΔE^*_{ab}, 3.8 ΔE^*_{ab} units, respectively, while those of intra-observer variability equal to 1.9 ΔE^*_{ab}, 2.1 ΔE^*_{ab}, 2.1 ΔE^*_{ab} units, respectively. The inter-observer variability in the naturalness experiment increased by 8.8% and in the preference experiment increased by 11.8% compared to the colourfulness experiment. The intra-observer variability in the naturalness and the preference experiment increased 10.5% compared to the colourfulness experiment. It can be found that colourfulness result showed a noticeable decrease in inter-observer and intra-observer variability.

Memory colour centre and ellipse

From the earlier studies, the memory colour centres were described as ellipses in *CIELAB* colour space. The ellipse model was derived in a matrix form and a polynomial form. Each observer's 'Yes decision' images were recorded. The results were in the form of 'Yes' and 'No'. They were arranged in the form of yes decisions rate Y%, which was calculated by the number of the yes decisions divided by the total number of observers multiplying by 100. *Y%* for each image was used to fit the tolerance ellipses under each ambient lighting. Equation (2) shows a logistic function to transform between the model predicted probability (Yp) and ΔE^*_{ab} calculated from an ellipse equation in *CIELAB* a^*b^* diagram. The ellipse equation defined the boundary corresponding to Yp equals 50%, i.e. half of the observers affirm the stimulus and the other half deny it.

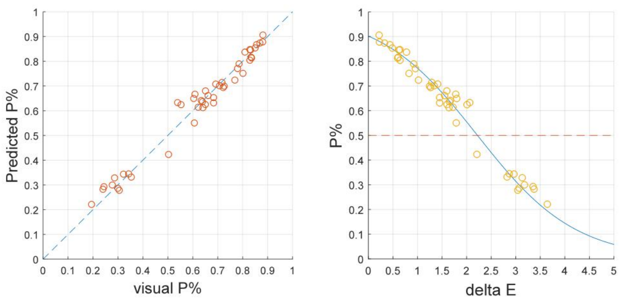
$$\mathrm{Yp} = \frac{1}{1+e^{(\Delta E^*_{ab}-\alpha)}} \qquad (2)$$

There are one method to build the ellipse or ellipsoid model. As shows in Equation (3), it simulates an ellipsoid model with skew angle only on a^*b^* plane in CIELAB colour space. An optimization process was established to obtain the coefficients, i.e. k_1, k_2, k_3, k_4, L_0, a_0, b_0 and α by maximizing the correlation coefficient between the *Yp* and *Y%*, which is the yes decision percentage from the visual results. Note that α is the colour difference calculated from the ellipse equation corresponding to 50% ellipse boundary.

$$\Delta E^*_{ab} = \sqrt{k_1(L-L_0)^2 + k_2(a-a_0)^2 + k_3(b-b_0)^2 + k_4(a-a_0)(b-b_0)} \qquad (3)$$

Performance of prediction model

In order to test the reliability of the model, Figure 4 and Figure 5 were plotted respectively to check whether the distribution of the original data is reasonable. As shows in Figure 4(a), the visual data and predicted data had a good positive correlation, and the correlation coefficient between them is 0.98. The curve in Figure 4(b) is the optimized prediction model. It can be seen that the experimental data are distributed around the prediction curve. Figure 5 shows the distribution of the fitted ellipsoid model and data points on CIELAB a^*b^*, a^*L^*, b^*L^* planes. The red plus sign indicates the data points with Y% higher than 50%, while the green cross sign indicates the data points with Y% less than 50%. It can be seen that almost all red data points were in the ellipsoid model, while green data points were distributed outside the ellipsoid model. This phenomenon is consistent with the physical meaning of the original assumption of the model.



(a) (b)

Figure 4. *(a) comparison of preferred model (P%) predicted result and the experimental visual result, (b) experimental preferred data (P%) distributed around the preferred prediction model.*

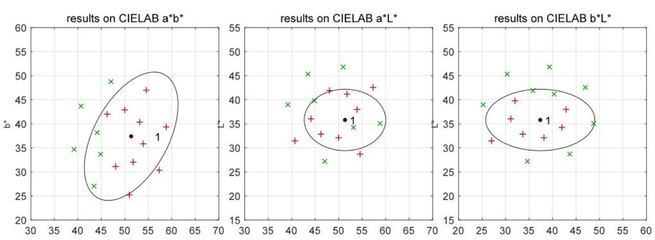


Figure 5. *'Yes' (red plus) and 'No' (green cross) choice result distribution and the model predicted memory colour ellipse.*

Preferred, colourful and natural result comparison

According to the above method, colourful, preferred, natural memory colour centre and ellipsoid of each image were processed. Figure 6 show a typical memory colour results of three attributes. It can be seen that the inclination and eccentricity of the three ellipses were very similar and the hue angle of the preferred memory colour and the natural memory colours were almost the same, but the position and size of the ellipses were slightly different. The distance from the origin point to the memory colour centre points was mainly in the chroma direction. The larger the distance, the higher the chroma of the colour. It can be seen that the chroma of the colourful memory colour is higher than that of preferred memory colour and higher than that of natural memory colour. To a certain extent, the size of the ellipse can indicate the observer's acceptance of a certain kind of attribute of memory colour. The size of colourfulness ellipse is larger than the naturalness ellipse. It proved that observer believes that the natural memory colour range is relatively small, while the observer believes that the colourful memory colour range is relatively large. Figure 7 was plotted to qualitatively analyze the correlation between the three attributes. There was a significant positive correlation between preference and naturalness, and the correlation coefficient between them was as high as 0.81. However, the correlation between preference and colourfulness is very weak, and the correlation coefficient was merely 0.56. This proved that the natural memory colour will be preferred by the observers, but the observers dislike the excessively colourful memory colour.

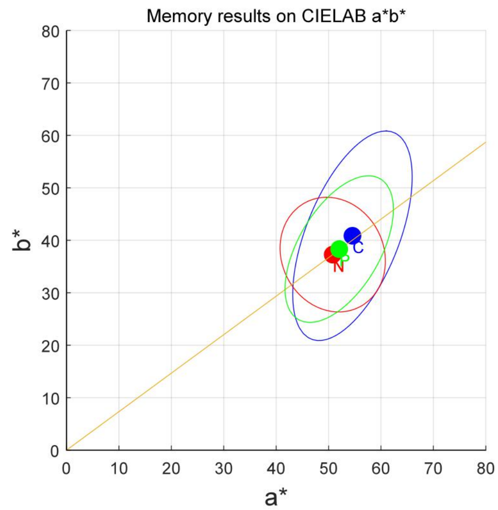


Figure 6. *Comparison of preferred (green), colourful (blue) and natural (red) memory colour centre and ellipse results of image 'strawberry' on CIELAB a*b* plane.*

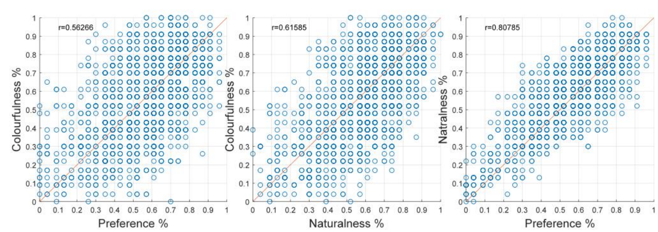


Figure 7. *Pairwise comparison of preference, colourfulness and naturalness*

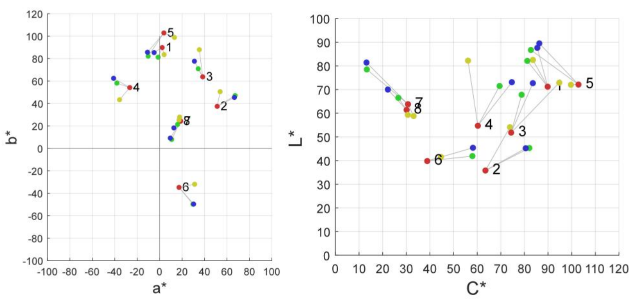
Comparison with previous results

To verify whether the experimental results of this model were reasonable, the preference data obtained in this experiment were compared with the experimental results of several groups of predecessors. As shows in Figure 8, the results were compared with the data of Zhu [23] , Kevin [21] and Bodrogi [22]. There were 8 memory colour objects (banana, strawberry, orange, green apple, lemon, lavender, Caucasian skin, Asian skin) used in all experiments. Due to the different fitting methods of the ellipse model and the memory colours described in different colour spaces, all colour centres were transferred into CIELAB colour space, as shows in Figure 8. Table 2 reports the mean CIELAB colour difference between inter-comparison results between 4 groups.

Overall, the mean colour difference is about 17 ranged from 5 to 22. Since the experiments from Zhu et al. And Bodrogi et al were exactly the same, the colour difference between the two groups of experimental results was very small. The Smet et al.'s memory colour results were obtained by the light projected by the projector illuminating on the surface of a real object. The Zhu and bordrogi's memory colour results were obtained by matching the colour in the images on a display. The present memory colour results were obtained by the alternative choice results of given memory colours. The color difference of memory color in different studies is largely due to the difference in experimental conditions used..

Table 2. colour differences (ΔE_{ab}^*) of the same objects in different studies.

ΔE_{ab}^*	*Ours & Kevin*	*Ours & Zhu*	*Ours & Bodrogi*	*Kevin & Bordrogi*	*Kevin & Zhu*	*Zhu & Bodrogi*
mean	**16.5**	**19.0**	**21.9**	**19.3**	**18.2**	**5.1**



(a) (b)

***Figure 8.**The memory colour centres of different studies (a) in CIELAB a*b* plane and (b) in CIELAB C*L* plane. The results of ours, Zhu's, Kevin's and Bodrogi's were showed in red, green, yellow and blue dots respectively.*

Conclusion

A psychophysical experiment was conducted to evaluate the preferred, natural and colourful memory colours of the most familiar objects on the mobile displays. The experimental data show that the inter-observer variation is MCDM=3.7, and the intra-observer variation is MCDM=2.1, both of which were within a reasonable range. Three methods were used to fit the experimental data, and the memory colour centres obtained from each method were almost the same. The shape of the ellipse was related to the method model. While M3 can fit a more perfect ellipsoid in the CIELAB colour space. The size of colourfulness ellipse is larger than the naturalness ellipse for all objects.. It proved that observer believes that the natural memory colour range is relatively small, while the observer believes that the colourful memory colour range is relatively large. The hue angles of the preferred memory colour and the natural memory colour were almost the same and the correlation coefficient between the two was as high as 0.81. The chroma of colourful memory colour was higher than preferred memory colour which was higher than natural memory colour. Comparing the memory colour centre of this study with previous results, the mean colour difference of 17. It confirms the rationality of the results of this research.

Acknowledgment

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Compliance with ethical standards

Conflict of interest: *The authors stated that they had no conflict of interest with the experimental subjects.*

Ethical Approval: *All the procedures carried out in the research involving human participants were in line with the Academic Rules of Engineering Graduates of Zhejiang University and 1964 Helsinki declaration and its subsequent revisions or similar ethical standards.*

Informed consent: *All individual participants included in the experiment were informed and agreed that the results of this study were used for academic research and publication of the paper.*

Author Biograph

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