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Huang, Y., Xu, Y., Yuan, J. et al. (2 more authors) (2023) Research on the interactive perception of color paper-cutting culture rendering based on AR. Journal of the Optical Society of America A, 40 (11). pp. 2059-2067. ISSN 1084-7529

https://doi.org/10.1364/josaa.491545

Research on the interactive perception of color paper-cutting culture rendering based on AR

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Abstract: To address the digital medium preference of the millennial generation, this study utilizes Augmented Reality (AR) technology for rendering color paper-cuttings by developing a mobile terminal based on Unity 3D and 3ds Max to demonstrate digital works scanned by paper-cutting entities. Three subjective scaling experiments are conducted to evaluate the aesthetics, viewership, and impression of four genres of digital color paper-cutting. The results show that observers have more preference for warm background with the maximum scaling value at the 7.5mm/s playback speed and a specific superimposed order. Importantly, current experimental design and interactive evaluation provide a reference for AR display parameters.

Keyword: Paper-cutting; Augmented reality; Mobile interaction; Perceptual evaluation; AR display

1. Introduction

As a national intangible heritage, paper-cutting, with its incomparable exquisiteness and unique style, is a crystallization of wisdom created and accumulated by the common people in their quest for a better life[1]. After countless generations of inheritance and development, on the basis of monochrome paper-cutting, more colorful and spiritual color paper-cutting techniques have been developed in China. Current four popular paper-cuttings with different art genres have gradually emerged[2]. For example, color dotting paper-cutting, color matching paper-cutting, color sketching paper-cutting, color pasting paper-cutting. In terms of color features, the color dotting paper-cutting always uses contrast colors as the main color relation, which has a brilliant and harmonious atmosphere, emphasizing the distinctive color hue of the work, while the bright colors used in the color pasting paper-cutting make the artwork present a strong visual impact[3]. The color matching paper-cutting is laminated with brightly colored paper on the back side of the hollow part of dark colored paper cutouts to present a picture with contrasting colors[4], while the color sketching paper-cut mostly draws gray and blue ink lines to create a natural and elegant atmosphere. In terms of creative techniques, color dotting paper-cutting is exquisite in color and has a strong traditional Chinese cultural flavour, while color pasting paper-cut combines a variety of color cutouts to present a mysterious, romantic, and exaggerated artistic effect. Meanwhile, the color matching paper-cut is first sketched and then carved out using the yin carving technique, and other color cutouts are pasted onto the hollowed-out part to create a contrasting spatial effect. Moreover, color sketching paper-cutting combines cutting and painting, using a brush to sketch on the semi-finished work to achieve a more delicate visual effect. Color dotting paper-cutting in Yu county (Hebei, China), color pasting paper-cutting in Xunyi county (Shanxi, China), color matching paper-cutting in Foshan city (Guangdong, China), and color sketching paper-cutting in Yantai city (Shandong, China) are all famous representatives of the color paper-cutting genres.

Recently, the scientific preservation and inheritance of intangible cultural heritage has received increasing attention from government policy to academic community[5]. However, color paper-cutting culture with regional characteristics is on the verge of being lost due to its requirement of superb skills and potent cultural innovation. In addition, if color paper-cutting is just illustrated in a two-dimensional plane, it would limit the artistic imagination and creative potential of its creators. As a result, the charm of color paper-cutting is only partially conveyed. Because the visual perception of current color paper-cutting is easily restricted by the hollow color contour within a flat plane. Therefore, more dynamic and multi-dimensional color paper-cutting renderings are the core challenges for the efficient heritage of the global paper-cutting culture.

The integrity of intangible cultural heritage information can be protected more efficiently for a long time by a new digital mode. By disseminating intangible cultural heritage in the digital medium, more people around the world can perceive its cultural connotation simultaneously[6]. It has been found that the dissemination of color paper-cutting culture can be more attractive by using digital media techniques which can provide aesthetic customization[7]. As a typical representative of digital medium technology, AR has emerged for rendering and interaction in recent years. Meanwhile, AR can transform text, image, video, sound and other data into virtual information to enhance the immersive experience of users in a realistic environment[8]. The virtual images in an AR display are provided by a light engine, such as LCoS (a reflective display that operates using polarized light)[9]. It can also contribute to easier management and better protection of intangible cultural heritage[10]. Practically, AR is used to turn mud goo goo (an ancient traditional folk craft) into a shared and renewable digital form, which plays an active role in the protection and inheritance of mud goo goo[11].

Meanwhile, virtual reality (VR) is another typical digital technology to utilize computer graphics simulating a fictional space where provides an immersive experience by VR devices. Perceptual interaction applications such as virtual museum, virtual artefact restoration, and virtual IP can be realized by specific VR tools[12]. Additionally, due to technological upgrades, some VR headsets are becoming affordable for the masses. However, there is a certain threshold for the general public to access digital intangible cultural heritage[13].

Compared with VR devices, most portable mobile terminals consisted of smartphones or pads can easily realize AR function to bring digital intangible cultural heritage closer to own

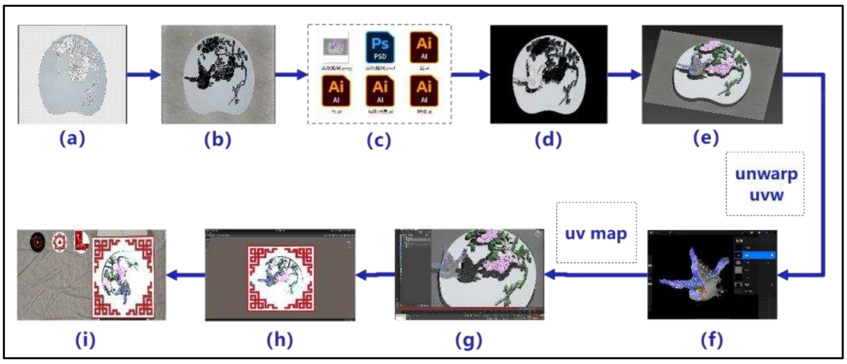

Fig. 1. Digital flow of key featires in color paper-cutting: a) using the wand or lasso to sketch the contours in Photoshop software; b) using the pen tool to incorporate details in Photoshop software; c) exporting AI format; d) extruding the models in 3ds Max software; e) importing Procreate software to paint; f) modifying 3ds Max

daily life[14]. Therefore, digital paper-cutting models were designed by considering the cultural elements of the above four major color paper-cutting genres. Additionally, this study will systematically explore optimization parameters to provide better perception of paper-cutting culture, such as hue & light, playback speed and superimposed order to create test samples for AR display perception evaluation. The statistical analysis of the subjective scaling values is to search the best interaction parameters for the display of color paper-cutting culture in AR, and to verify the feasibility of AR parameterized adjustment.

2. Digital realization of key features in color paper-cutting

2.1 The digital flow of key features in color paper-cutting

The digital implementation of color paper-cutting samples contains three main processes: drawing the cutting paths in Photoshop software (Adobe, America), designing corresponding 3D color models and generating animations in 3ds Max software (Autodesk, America), and conducting AR interactive test in Unity 3D software (Unity Technologies, America). The Fig.1 shows the digital flow of a color dotting paper-cutting sample, and the process of preparing samples of other styles is similar.

2.2 Digital model design of four genres of color paper-cutting

The Fig.2 shows four genres of color paper-cutting, the first row is handicraft cases and the second row is the corresponding digital models designed with the distinctive features of different cultural expressions.

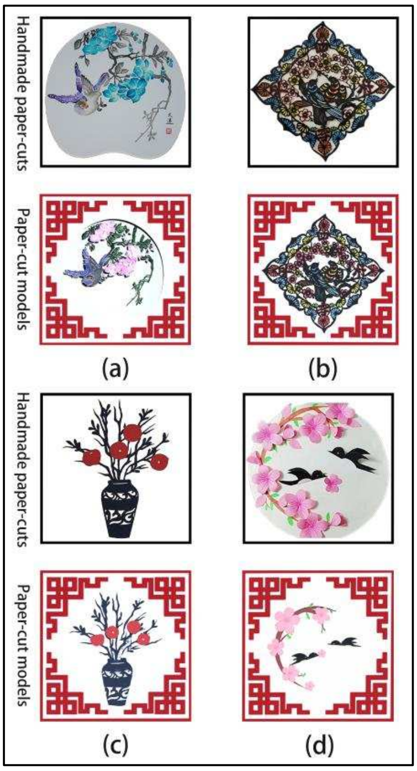

Fig. 2. Four genres of test digital cases of color paper-cutting: a) color dotting paper-cutting; b) color matching paper-cutting; c) color pasting paper-cut; d) color sketching paper-cutting.

2.2.1 Digital model design of color dotting paper-cutting

For the sake of achieving a better effect of finesse color transition, color dotting paper-cutting often uses three or four colors for dotting or drawing. Dipping the pigment into the rice paper and combining it with other brush processes including kneading, wiping, dropping, skimming and picking for point-by-point features to show the unique artistic effect of the painted image with colorful and emotional rendering.

This study uses contrasting colors as the main color relationship, such as the main colors of B (bluish-violet) and A (pink) in Fig.3, and choose the brush in Procreate (Apple, America) to paint. In addition, the artist uses three or four colors consisted of similar colors or adjacent colors to simulate the authentic dotting effect in ink painting. Our color paper-cutting model uses three similar colors to coloring the bird with the underlying ink gray, and select dark blue and purple to deepen the details. The colorimetric values of flowers and birds are shown in Fig.3(a) &(b).

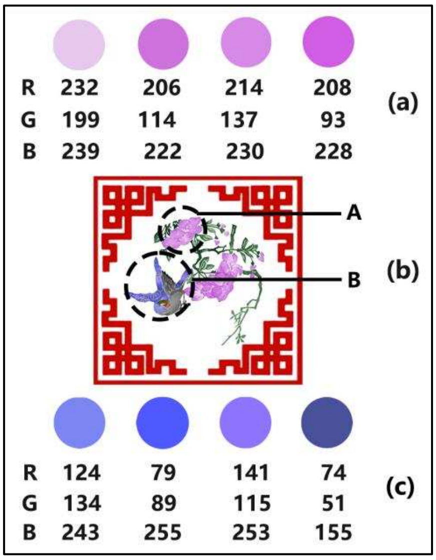

Fig. 3. The RGB values of digital model of color dotting paper-cutting: a) the flower; c) the bird.

2.2.2 Digital model design of color matching paper-cutting

For a color matching paper-cutting sample, the solid-color paper is prepared to carve out the lines and skeleton of the object, and then paste other tailored color paper corresponding to its rest hollowed-out area. At last, the outlines of different colored elements are regularly stacked together to create a contrasting image. In this study, the superimposed order of color elements is the core feature of color matching paper-cutting samples. First of all, this section create a new blank layer as a skeleton layer, next use the pen tool in Photoshop software to draw lines and skeletons, and fill them with black color. Subsequently, create a new layer under this layer as a color layer and use the brush tool to fill the hollowed-out area with specific colors. Finally, import relative elements into 3ds Max and place the color layer behind the skeleton layer to simulate the visual effect of superimposition in color matching paper-cutting. Its original case is shown in Fig.2(b) and its corresponding test samples are shown in Fig.9 and Fig.11, respectively.

2.2.3 Digital model design of color pasting paper-cutting

In the case of color pasting paper-cutting, the biggest artistic feature is the large black outline layer with pasted certain small color elements in the front. Then, some small color paper-cuttings are added to its front making the overall image richer to show a powerful visual effect. In this study, the color pasting paper-cutting model contains two parts: the main black body and the color embellishment. This helps to simulate pasting color cutouts on the main part during the animation. Its original case is shown in Fig.2(c) and its corresponding test samples are shown in Fig.9 and Fig.11, respectively.

2.2.4 Digital model design of color sketching paper-cutting

For the color sketching paper-cutting, a sketch is drawed on the color paper cut with a pencil at first, then the rough outline of the essential creative shapes with scissors is cutted to paste all the necessary shapes by this method. Next, a brush pen following the pasted outline is used to make it clear and distinct, and finally coloring it with a lifelike style. In this study, the sketch is generated by rendering UV template of flowers & swallows. Its original case is shown in Fig.2(d) and its corresponding test samples are shown in Fig.9 and Fig.11, respectively.

2.3 Implementation of AR functional elements of color paper-cutting

2.3.1 Animation generation

The animation generated in this study is adopted the PAL (Phase Alteration Line, a format has 25 frames per second), and unified the animation time to 8s, which is convenient to control the displacement variables to calculate the position coordinates of the model. Since 3ds Max cannot directly calculate the movement speed of the digital model, so it is necessary to manually input the initial and final XYZ coordinates of the digital model to achieve the unified speed. Then, the flow chart of animation generation of color paper-cutting samples is shown in Fig.4.

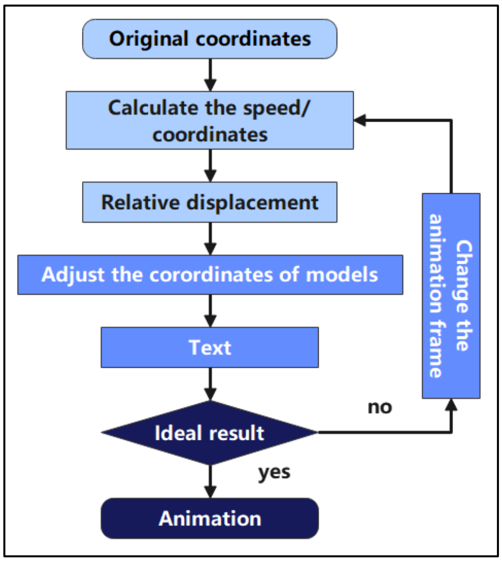

Fig. 4. The flow chart of animation generation of color paper-cutting cases.

2.3.2 The main process of proposed APP development

The digital models of color paper-cutting in fbx. Format is imported into Unity 3D software and further developped by the "Vuforia SDK" (Parametric Technology Corporation, America) for the proposed APP, with the following steps, also shown in Fig.5.

Step 1: Upload the prepared paper-cutting images to the Vuforia server and download the database generated by the system, then import it into Unity 3D software.

Step 2: Create a new "AR Camera" and "Image Target", and then delete the original "Main Camera" and "Directional Light".

Step 3: Set the "Type" in "Image Target Behaviour" (Script) to "From Database", select the imported data package for the "Database", and select the recognition image corresponding to the paper-cutting for the "Image Target".

Step 4: Set the paper-cutting models as a sub-object of the "Image Target" and adjust the size and position of the models to be consistent with the paper-cutting images.

Step 5: Activate the "Emission" when adding material to the paper-cutting models, and drag the UV map of the material into the small frame of "Color" to ensure that the rendered models will not be affected by the light.

Step 6: Create a new "Animator" to set the animation playback function, and freeze the "Has Exit Time" function to achieve the effect of playing the animation when the button is clicked, preventing the delay from bringing a bad experience.

2.4 The perceptual evaluation experiment of AR color paper-cutting models

To improve the AR interaction experience of color paper-cutting models, three types of subjective scaling experiments were conducted in this study. A total of 16 standard observers are

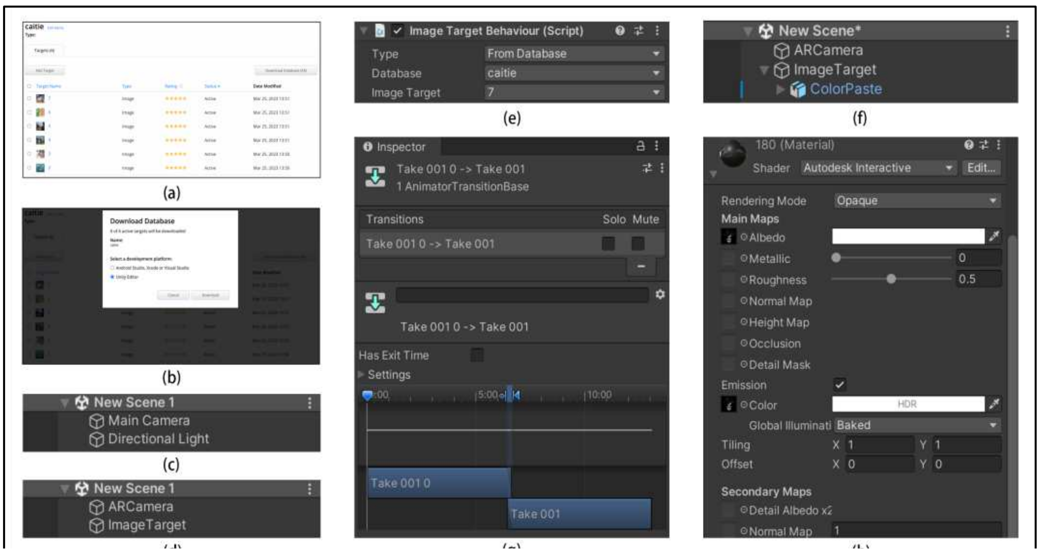

Fig. 5. Developing the proposed APP for AR rendering of color paper-cutting models.

invited to this experiment, among whom the ratio of male to female is 3:1. The age of each observer is between 20-25 years old, whom is the college student with normal vision. During the entire experimental phase, each observer is in a good mental state with the auxiliary test positioning device which could reduce the interference of visual fatigue.

In this study, the hue and light of background color, playback speed of the animation, and superimposed order of AR rendering of color paper-cutting models are regularly adjusted and evaluated from three aspects: aesthetic, viewership and impression, and the specific experimental design is shown in Fig.6. There are five levels of aesthetics: ugly, unaesthetic, common, beautiful, and gorgeous; five levels of viewership: poor, unperceptive, ordinary, good, and excellent; five levels of impression: terrible, unimpressive, general, great, and memorable. Each level is referred to a specific grade using the MOS(mean opinion score) value shown in Table 1[15].

In this study, the following two equations are used for the corresponding numerical analysis. The Eq.1 will be averaged over all MOS values for aesthetic, viewership and impression. The Eq.2 performs statistical analysis using different weights for different perceptual features.

$$\bar{X} = \frac{1}{n} \times \sum_{i=1}^{n} x_i \quad (1)$$

$$\bar{Y} = \frac{1}{n} \times \left(\sum_{i=1}^{n} 0.5m_i + \sum_{i=1}^{n} 0.2n_i + \sum_{i=1}^{n} 0.3l_i\right) \quad (2)$$

Where $\bar{X}$ is the average MOS value, x_i is the original MOS value for perceptual features, $\bar{Y}$ is the integrated scaling value, m_i is the average MOS value for aesthetic, n_i is the average MOS value for viewership, l_i is the average MOS value for impression. There are three reasons for the tunable allocation of weights in Eq.2. Firstly, the aesthetic of color paper-cutting models is the most important perceptual feature in this study, which can

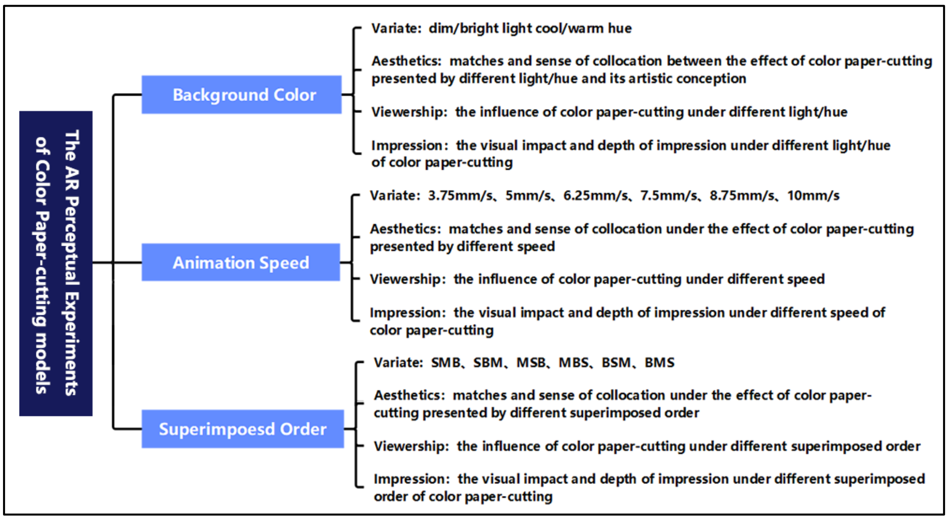

Fig. 6. The evaluation criterion of three experiments.

Table 1. The MOS value corresponding to the scaling grade of aesthetics, viewership and impression

MOS value	Category		
	Aesthetic	**Viewership**	**Impression**
2	Ugly	Poor	Terrible
4	Unaesthetic	Unperceptive	Unimpressive
6	Common	Ordinary	General
8	Beautiful	Good	Great
14	Gorgeous	Excellent	Memorable

provide a precise guide for aesthetic rendering of AR color paper-cutting. Secondly, exploring the evaluation of standard observers on the viewing experience of AR color paper-cutting is good for the best viewing angle design with different AR devices. At last, investigating whether AR color paper-cutting impresses the standard observer could inspire innovative designs of color paper-cutting models.

3. Interactive perception analysis of AR color paper-cutting models

This study utilizes the sRGB color space to ensure more consistent color representation across different digital devices. The experimental platform is smartphones, and the resolution of this application is 1080x2400, as it is commonly used in the current smartphones. This target color performance offers a higher pixel density, allowing for a more delicate and vivid paper-cutting effect. Users can experience a more realistic sense of spatial depth and appreciate the beauty of paper-cutting art while enjoying the application.

In this study, prior to the start of the formal evaluation experiment, each standard observer will be provided with an explanation and demonstration, and guided to interact with the paper-cutting AR application and rotate the AR model to observe its hierarchical order and spatial structure. This step ensures that each observer has a comprehensive understanding of the different viewing perspectives of the color paper-cutting AR models prior to the formal experiment.

During the formal experiment, to comprehensively analyze the effects of the three mentioned-above key parameters, a single-variable factor analysis was used to conduct a controlled experiment incorporating a primary viewpoint of the AR paper-cutting surface with full image content, whereby a fixed perspective (front view) of the projected object was chosen for the subjective scaling.

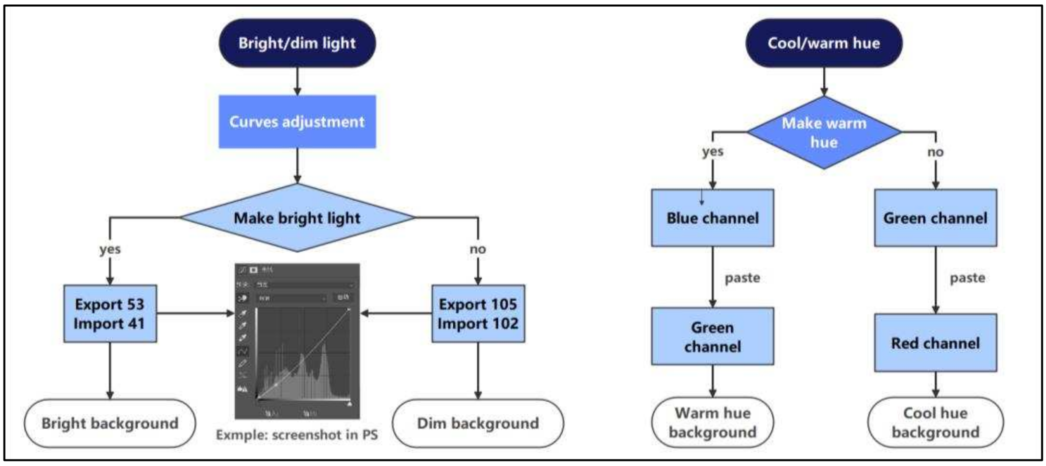

Fig. 7. The generation flow of test samples modified light and hue attributes.

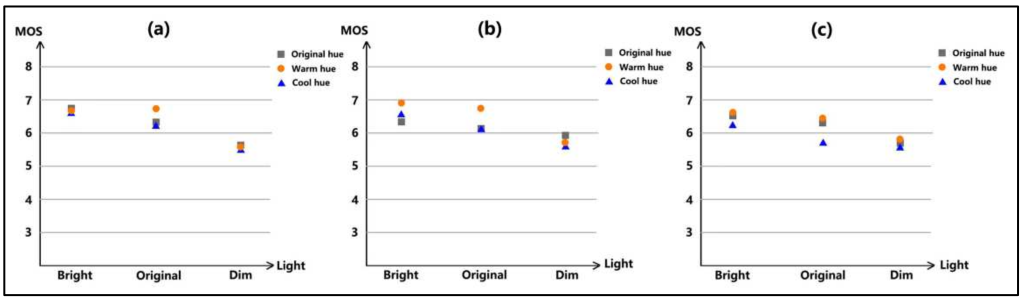

Fig. 8. Perception assessment of the hue and light of test background color: a) the MOS values for aesthetic; b) the MOS values for viewership; c) the MOS values for

3.1 Perceptual evaluation of the hue and light of background color

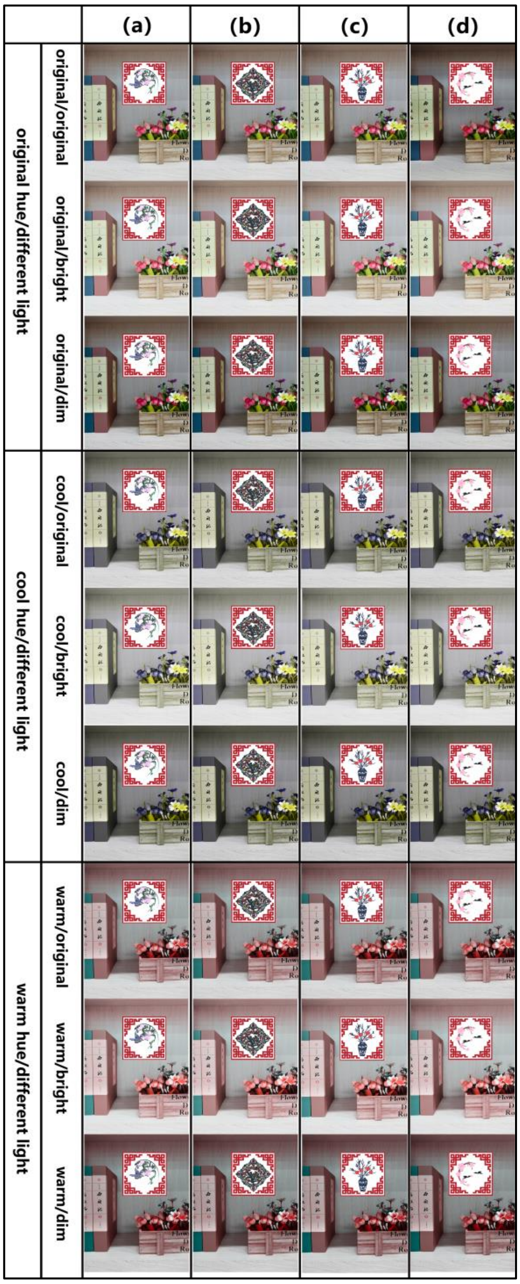

Fig. 9. Summary of Different Light and Hue: a) color dotting paper-cutting; b) color matching paper-cutting; c) color pasting paper-cutting; d) color sketching paper-cutting.

The AR can provide the integrated interaction between virtual and reality. Therefore, the, hue and light used in the scene background greatly influence the rendering effect of AR color paper-cutting models. To explore the best rendering effect, this experiment takes the desk as the scene background, with three test groups of hue attributes and light attributes. The hue attributes are consisted of original hue, cool hue, and warm hue, while the light attributes are consisted of original light, bright light, and dim light. Different test samples combined hue with light are generated by adjusting the color curves of original UV texture with the predefined values, and corresponding process flows are shown in Fig.7. The perception assessment of the hue and light of test background color are shown in Fig.8. The data in Fig.8 are the mean MOS values of four genres of AR color paper-cutting models. The summary of different light and hue are shown in Fig.9.

As can be seen from Fig.8, in the perceptual evaluation of aesthetics, viewership, and impression, the average MOS values decrease with decreasing background light, indicating that a bright background is more suitable for presenting AR color paper-cutting designs. In most cases, the MOS values for warm hue is the highest. This is because warm hue backgrounds are more vibrant compared to original hue or cool hue backgrounds, which not only bring a lively and tender feeling but also easier to attract viewers' attention, resulting in a better visual experience for AR color paper-cutting designs. However, in dim light, the warm hue background with rich colors makes the image appear dirty, which spoils the presentation of AR color paper-cutting designs, leading to a lower MOS value.Studies have shown that bright light and warm hue backgrounds have a positive impact on visual effects, elevating the presentation of paper-cutting designs in AR and aligning with the aesthetic tastes of the public, thus giving rise to the artistic charm of the fusion of emerging technologies and traditional culture.

3.2 Perceptual evaluation of the playback speed of AR color paper-cutting

The superimposed order of AR color paper-cutting in this perceptual evaluation experiment is Small-Middle-Big.

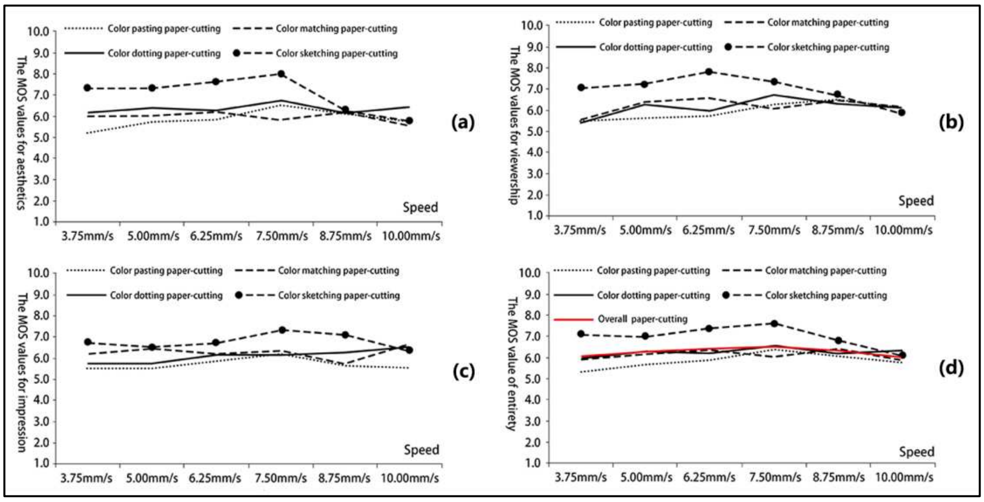

Fig. 10. Perception assessment of test playback speeds of AR cases: a) the MOS values for aesthetic; b) the MOS values for viewership; c) the MOS values for impression; d) the MOS values for comprehensive perception.

Table 2. The full name corresponding to the abbreviation

Abbreviation	SMB	SBM	MSB	MBS	BMS	BSM
Full name	Small-Middle-Big	Small-Big-Middle	Middle-Small-Big	Middle-Big-Small	Big-Middle-Small	Big-Small-Middle

Clearly, either too slow or too fast playback speed has a bad effect on the aesthetics of AR color paper-cutting, as shown by the MOS value for aesthetics rising and then falling with increasing speed in Fig.10(a). The color pasting paper-cutting and the color sketching paper-cutting obtained the maximum MOS value for aesthetics at 7.5mm/s. Due to the bright and vivid colors of the color pasting paper-cutting and the color sketching paper-cutting, their lively aesthetics characteristics are more distinctly reflected by faster speed. From Fig.10(b), the low MOS values for viewership at speeds of 3.75mm/s and 10mm/s indicate that excessively slow speeds will make the animation dull, while too fast speeds will cause visual confusion, both of which are unfavorable for the viewership of animation. As shown in Fig.10(c), the MOS value for impression does not change significantly as the playback speed of the paper-cutting animation increases from 3.75mm/s to 10mm/s. Consequently, this playback speed change will not cause a significant difference in the impression of the animation in the viewer's mind. As can be seen in Fig.10(d), different styles of color paper-cutting have different optimal animation playback speeds, and the MOS value for comprehensive perception of overall paper-cutting increases slightly as the speed increases, peaking at 7.5 mm/s and then decreasing. In general, the animation speed of 6.25-8.75mm/s is the most appropriate and more conducive to a better visual experience of AR color paper-cutting.

3.3 Perceptual evaluation of the superimposed order of AR color paper-cutting

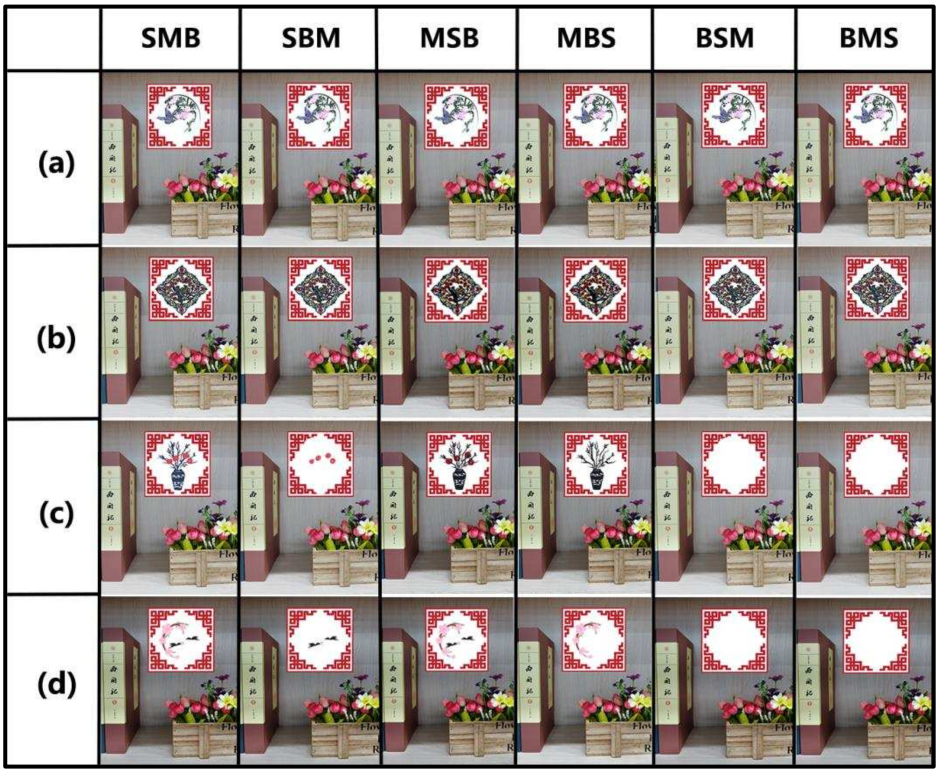

Fig. 11. Summary of different superimposed orders: a) color dotting paper-cutting; b) color matching paper-cutting; c) color pasting paper-cut; d) color sketching paper-cutting.

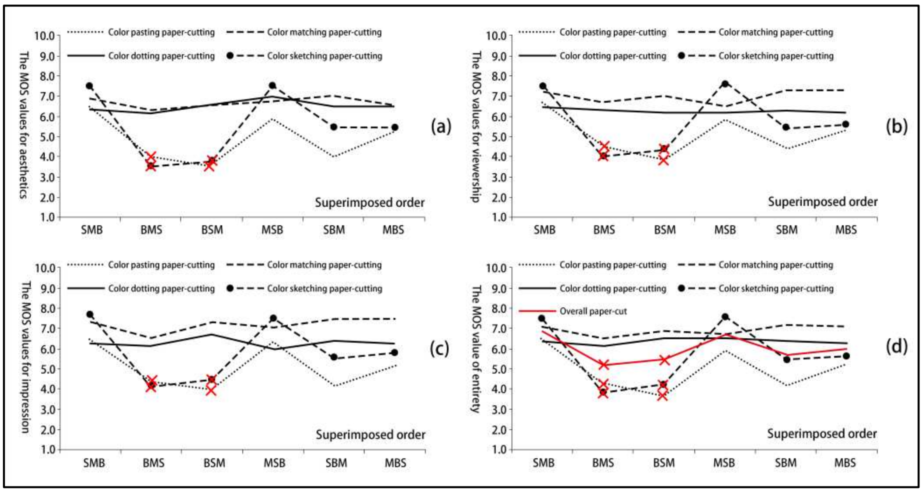

Fig. 12. Perception assessment of test superimposed orders of AR cases: a) the MOS values for aesthetic; b) the MOS values for viewership; c) the MOS values for impression; d) the MOS values for comprehensive perception.

As a special visual design element, the superimposed order is one of the factors affecting the overall rendering effect of AR color paper-cutting. Thus, with respect to the animation rendering of different paper-cutting models, the superimposed order of the key elements can affect the interactive AR experience of the user. Moreover, this can also be influenced by different genres of color paper-cutting, so this study tests six superimposed orders of rendered samples for quantitative analysis, as shown in Table 2 and Fig.11. Finally, the comprehensive MOS values of test samples are illustrated in Fig.12. It can be observed from Fig.11 that when the superposition order is BSM and BMS, the color pasting paper-cutting and the color sketching paper-cutting are completely blocked, losing their evaluative significance. Therefore, the analysis and evaluation of different superposition layers of AR color paper-cutting did not include the points marked with a red "X" in the Fig.12, which were completely obscured. The playback speed of AR color paper-cutting models in this perceptual evaluation experiment is 7.5mm/s.

As shown in Fig.12(a)-(c), the MOS values of the color pasting paper-cutting and the color sketching paper-cutting are highest when they are superimposed in the order of SMB, while the MOS values are lower in the superimposed orders of MSB, SBM, and MBS, where some elements are occluded. This is because the integrity and overall logic of the paper-cutting animation is damaged when the paper-cutting elements are blocked, which affects the animation rendering effect. However, this situation is not absolute. Take the color dotting paper-cutting for instance, in Fig.13(b), the bird is flying inside flowers, which is consistent with natural phenomena. Therefore, although the bird is occluded by the flowers, its interactive perception is still higher, which has a positive effect on the presentation of the effect of the AR color paper-cutting. On the whole, when designing the superimposed order of AR color paper-cutting animations, the superimposed order of SMB is the best. If occlusion occurs during animation, it is necessary to consider whether the masking of paper-cutting elements is reasonable, and ensure the completeness of the animation content, in order to achieve better aesthetics, viewership, and impression effects[16].

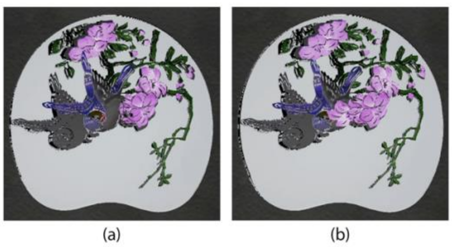

Fig. 13. The color dotting paper-cutting's superimposed orders of SMB and MSB: a) SMB; b) MSB.

4. Conclusion

Taking the heritage of color paper-cutting with Chinese cultural features as an example, this study explores the perceptual experience of digital color paper-cutting models under AR rendering based on the developed functional APP. When evaluating the current test samples of the four major color paper-cutting genres, this study conducted a quantitative analysis using a total of three major perceptual attributes: aesthetic, viewership, and impression. The background with bright light or warm hue can make a positive impact on the visual effect of AR color paper-cutting. By summarizing the perceptual evaluation of AR color paper-cutting animation by standard observers at speeds ranging from 3.75mm/s to 10mm/s, it was found that the animation speed of 6.25-8.75mm/s is the most appropriate and more conducive to a better visual experience of AR color paper-cutting. By summarizing the perceptual evaluation of AR color paper-cutting by standard observers at different superimposed orders, it was found that SMB is generally the ideal superimposed order for AR color paper-cutting. Besides, the results indicated that the data fluctuations for the superimposed order groups were significantly larger than those for background color and play speed. This suggests that the superimposed order has the most significant impact on the standard observer during the formal perceptual process. Therefore, when designing color paper-cutting AR samples, superimposed orders should be prioritized to ensure users can obtain the best visual experience.

Therefore, the development of this system not only provides reference for the derivative design of color paper-cutting culture and AR perception, but also realizes the protection and dissemination of intangible cultural heritage in a digital way. Moreover, this system also exhibits strong scalability, as it can be used to evaluate and showcase various digital contents, such as artworks, shadow plays, mythological characters, and more. The influence of cultural differences may lead to different perceptual results, and the significance of the assessment variables determines the value of the experiment. It is crucial to integrate the elements related to the content itself with their corresponding cultural context and identify the variables that genuinely impact perception. Building a sample database for real-time, high-quality perceptual evaluation of AR applications for color paper-cutting would be a valuable research focus, and it could also provide more intelligent perceptual experiences for the digital inheritance of other intangible cultural heritage.

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Author Contributions: Yuchen Huang, validation, software, visualization, investigation, writing—original draft preparation; **Yulei Xu**, methodology, formal analysis, writing —original draft preparation; **J.P. Yuan**, conceptualization, project administration, funding acquisition, resources, supervision; **Chaoyuan Zan**, software, visualization; **Kaida Xiao**, writing—review and editing.

Funding: This work has been financially supported by the National Natural Science Foundation of China (Grant No. 61973127), Guangdong Provincial Science and Technology Program (Grant No. 2017B090901064), and Young Scholars Launching Fund (Grant No. 10-00-309-008-01) .

Conflicts of Interest: The authors declare no conflict of interest.