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OPERATIONS, INFORMATION & TECHNOLOGY | RESEARCH ARTICLE

A mobile application for personal colour analysis

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Abstract: This study developed a mobile app of the personal colour analysis system, which determines the clothing colours that are harmonized to a user's personal skin and hair colouring. The mobile application is easy and accurate for non-experts to use, and it employs photographs of a user's skin and hair colours to automatically calculate and categorize personal colouring instead of using fabrics as an analysing material. The application applies virtual packets of fabric swatches to virtual tee shirts and overlays them on the user's photographs to obtain a personal colour analysis. Through this process, the application reduces personal time and cost dramatically, and it allows users to analyse their personal colours repeatedly by themselves. This study is expected to establish a framework to advance research on clothing colours. The application is also expected to substantially assist consumers in choosing clothing colours.

Subjects: Design; Fashion Design; Design; Cultural Studies; Fashion

Keywords: colour matching; mobile application; personal colour analysis

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PUBLIC INTEREST STATEMENT

This study developed a personal colour analysis system, which finds the clothing colours that are harmonized to a user's personal skin and hair colouring. The mobile application is easy, fun and accurate for everyone to use, and it employs photographs of a user's skin and hair colours to automatically calculate and categorize personal colouring instead of going to a style consultant. The application applies virtual packets of fabric swatches to virtual tee shirts and overlays them on the user's photographs to obtain a personal colour analysis. Through this process, the application reduces the personal time and cost dramatically, and it allows users to analyse their personal colours repeatedly by themselves. This study is expected to establish a framework to advance research on clothing colours. The application is also expected to assist consumers in choosing clothing colours substantively.

1. Introduction

Clothing is a method used to communicate information about impression formation and social perception or effect on behaviours (Burns & Lennon, 1993; Goffman, 1959; Johnson, Yoo, Kim, & Lennon, 2008; Kwon, 1992; Lennon & Davis, 1989). Especially, clothing colour is a significant factor for communication with self and others. Some previous studies have found that clothing colours that harmonize with an individual's physical characteristics, such as the person's skin or hair colour, actually increases that individual's physical attractiveness and self-esteem to create an engaging first impression (Jackson, 2011; Nicholson & Lewis-Crum, 1986; Revelli, 1982) and increase the possibility of obtaining employment (Gibson & Balkwell, 1990). Mahannah (1968) discovered that clothing colours are important factors for creating first impressions, and clothing colours are more important in that respect than facial expressions or clothing styles (Radeloff, 1990). Since the 1990s, the colour-in-context theory has developed in psychology, and studies have been conducted on clothing colours in certain contexts, most of which concerned red clothing. These studies found that men identified women dressed in red shirts as more attractive than those dressed in other colours (Elliot & Niesta-Kayser, 2008; Guéguen, 2012; Guéguen & Jacob, 2012; Niesta-Kayser, Elliot, & Feltman, 2010), suggesting that red clothing is attractive to men. However, Lynn, Giebelhausen, Garcia, Li, and Patumanon (2016) claimed that servers dressed in red perceived relatively lower attractiveness than those dressed in white or black. This inconsistency that indicates a need for further research on clothing colours. One reason for the conflicting research findings on clothing colours might be that a certain clothing colour might suit some people's colouring better than others, and, therefore, even when they wear the same colour, different impressions might result because of individual differences.

The tool used to identify the colours that best match individuals' natural colouring is called personal colour analysis system. The term of personal colour analysis, also known as colour analysis, seasonal colour analysis, or skin-tone matching, has been often used in the fashion and cosmetic industry. It is used as a method of analysing the colours of clothes and makeup that harmonize with a person's skin, hair, or eye colours for fashion styling or image consulting. Starting in the 1970s, a number of researches proposed systems of colour analysis for discovering which shades of colour in clothes or makeup complement personal natural colouring to look healthier, sexier and more powerful (Jackson, 1984). Colour analysis demonstrates how certain shades on the body or face are capable of being hospitable for or, conversely, hostile to a perceiver. It is generally agreed that concordant colours will enhance the attractiveness of the individual compared with discordant colours.

Most of the personal colour analysis systems had divided the colours into four groups of harmonious colours with an individual's skin, hair or eye colours. Researchers arbitrarily specify the names of the group, but commonly matched with the four seasons of the year as called seasonal colour analysis. Seasonal colour analysis associate individual colouring into the tonal groupings of Winter, Spring, Summer, and Autumn, or their sub-variants. However, the results can be altered regarding each researcher or expert. Some colour analysis systems classify an individual's skin, hair and eye colour combinations using labels that refer to a personal colour's temperature—cool tone and warm tone. In an attempt to move away from the complexities and inexactitude involved in the early colour systems, Cognac's Essential Colors, Nicholson and Lewis-Crum (1986) and Flusser (2002) have suggested that it is possible to achieve attractive based on the level of contrast between a person's skin tone, hair and eye colours. Since the 1970s, variations of this system have been developed. Nonetheless, most of the systems still require expert analysis with complexities. Because the analytical results depend on expert opinions that might vary, the recommendations of colours might be inconsistent (Collin, 1986). A second drawback to the use of experts is that the system is limited by time and space, and the further problem is that the system cannot be accurately used when the colours of the fabrics used in the analysis are discoloured or contaminated.

Despite its weaknesses, some studies have found that the personal colour analysis system is effective. Radeloff (1990) compared images of models dressed in colours that match their physical

colouring to images of them dressed in colours that did not match. He used the seasonal colour system (Caygill, 1980) and the best colours of each type (Jackson, 1980) and found that an individual might appear relatively more attractive when dressed in personalized colours that match her or his colouring. However, Francis and Evans (1988) found that one of the two shades of red recommended by the Commercial Color Analytical System received good feedback for employment possibilities. Thus, despite the positive effects of personalized colours, most of the recent studies on clothing colours did not consider the importance of ensuring that colours suited the subjects' colouring.

The values and chroma of a clothing colour influence first impressions as well as that colour's shade, and studies have found that men are more likely than women to prefer colours in a high chroma (Radeloff, 1990). Moreover, Francis and Evans (1988) determined that colour value had a stronger influence than shade (hue) on college recruiters' evaluations of students' employability. Francis and Evans (1987) also found that after hair colour, changes in the value of clothing colours had the strongest influence on evaluations of individuals' traits, and bright colours tended to give more positive impressions than dull colours.

In light of these findings, studies on clothing colours should consider whether they match individuals' characteristics as well as compare among colours, and, to that end, studies should examine the effects of hue as well as value and chroma. Recent studies on clothing colour have tended to focus on hue by comparing red to other colours, which is unimportant to consumers interested in non-red clothing.

Personal colour analysis regarded with affection by people in general in the early 1980s and tended to rise again in the 2010s after further progress and promotion of different versions by image and colour consultants worldwide. The personal colour analysis is a useful standard for studying the influences of changes in the values and chroma of clothing colours, and it provides substantial help to consumers when they purchase clothing (Solomon, 1985) because it offers consumers a variety of hues and tones.

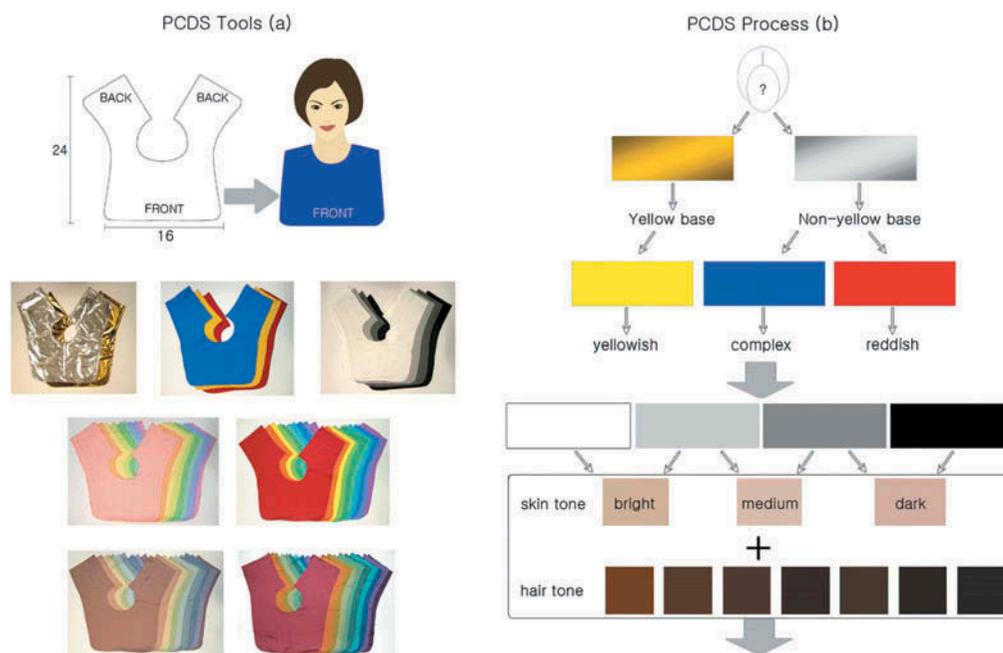
The successful practical colour analysis will theoretically allow people to harmonize their clothing and make-up with benefits and avoid costly mistakes by purchasing products within recommended colours. However, most of the colour analysis methods developed in the 1980s are difficult for non-experts to implement. Non-experts are forced to depend on expert opinions that are time-consuming, costly, and often are inconsistent. However, colour analysis has continued to be problematic and controversial due to the lack of standard training systems required to be a professional colour analyst. Results depending on various levels of personal colour experts can charge the cost for the individual, both concerning the fees of professional and less than professional analyses and subsequent clothing and cosmetics purchases. Thus, this study developed a personal colour analytical application for smartphones to enable non-experts to analyse their personal colours easily and accurately based on their colouring.

2. Mobile application design

2.1. Personal colour analysis system

Among recent versions of personal colour analysis systems, this study employed the Personal Color Design System (PCDS) (Kim, Lee, & Kim, 2003), which was developed to match colours based on the level of contrast between skin and hair colours of Korean women. The PCDS is a sensory evaluation method that requires analysis by colour experts. The PCDS' tool comprises 16-inch × 24-inch colour fabrics to be placed on the subjects' shoulders. The fabrics are gold, silver, yellow, blue, and red, and there are four achromatic colours with ten best shades of each achromatic colour (Figure 1 (a)). Personalized colours are analysed based on the contrast between the dyed fabrics on the subjects' shoulders and the subjects' skin tones.

Figure 1. PCDS tools (a) and process (b).



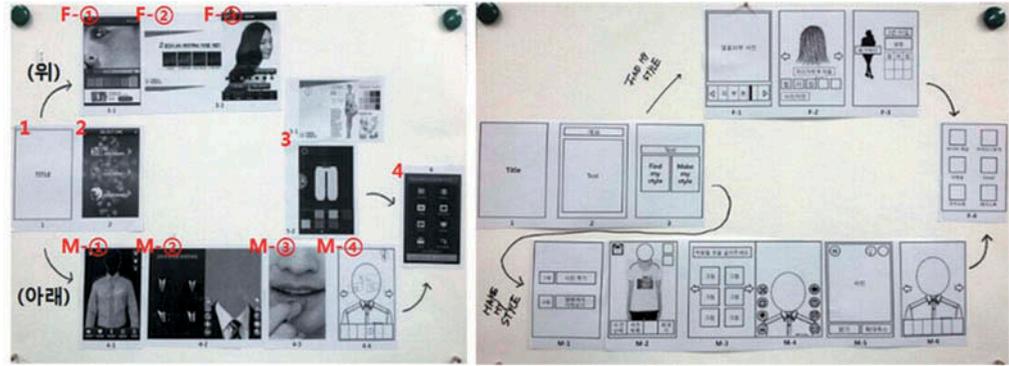
The PCDS categorizes subjects into four personalized colour types: Star, Sun, Moon, and Sunset. In the first categorization step, an expert places gold and silver fabric on a subject's shoulders and compares the colours regarding harmony with the subject's skin tone and identifies the skin tone as having a yellow or red base. The second step is to precisely categorize the subject's skin tone as yellow base, red base, or combination by comparing it to yellow, blue, and red fabric swatches. The third step categorizes the subject's skin tone as light, medium, or dark by comparing it to the achromatic fabric swatches. Last, the skin tone is categorized as Star, Sun, Moon, or Sunset based on the contrast between the subject's skin and hair colours. Then, ten colour fabrics of each of the four types are placed on the subject's shoulders. The six swatches that best match the skin and hair colours are recommended to the subject (Figure 1(b)). Thus, like the other colour analysis systems, to identify someone's colour type with the PCDS, he or she has to make an appointment with a colour consultant, visit there and pass through all the complex steps and even pay quite a lot. To avoid these inconveniences to customers and guide to the most accurate results for consultants, the PCDS provides standard guidelines and samples for personalized colour analysis based on the skin tones and hair colours of Korean women from the studies (Lee, Kim, & Kim, 2003). However, there is no standard training courses or degrees to become an expert about PCDS. Therefore, not only the guideline but also the PCDS has not been effectively used.

3. Design process

This study designed the mobile application to fit Google Android OS, which has at least 80% of the global market share so that a large percentage of smartphone users could use it (Molla, 2017). Before developing the application, we collected and analysed data on about 105 applications with similar functions available in the Google Play Store. The first diagram in Figure 2 (left) was created based on these data, and technical advice was sought from two mobile application developers on converting it into an application, after which the compositions and functions were modified for technological implementation. Then, after seeking advice from colour experts, the PCDS tool was used to develop the second diagram in Figure 2 (right).

When development was complete, two workshops were held to verify the usability of the application. The workshops' objective was to assess the extent to which users found the application convenient and the extent of their satisfaction with the application through interviews and

Figure 2. The first (left) and second (right) diagrams.



a survey with questions about icon size, location, and colour. The first workshop included 48 participants and was held on 11 December 2013, at the Asia Color Association Conference at Rajamangala University of Technology, Thanyaburi, Thailand. The second workshop was held on 4 March 2014, to assess the final design, and 27 Yonsei University students in Korea participated.

3.1. Differences between the PCDS and the mobile application

3.1.1. PCDS analysis guidelines

The mobile application does not use experts to analyse personalized colours; instead, the analysis is based on the PCDS guidelines. In these guidelines, the typical skin tones of Korean women are categorized as based on yellow, red, or combination and as light, medium, or dark, comprising nine possible skin colours. Hair colours consist of seven shades based on hue. By combining the typical skin and hair colours, four basic categories were created (Star, Sun, Moon, and Sunset) and 12 precise types were subdivided: Yellow Star, Yellow Sun, Yellow Moon, Yellow Sunset, White Star, White Sun, White Moon, White Sunset, Pink Star, Pink Sun, Pink Moon, and Pink Sunset (Table 1).

3.1.2. Colour conversion

We loaded the typical skin and hair colours and all of the PCDS colours into L*a*b* and RGB using the Munsell Conversion Program for developing the digital application (Table 2).

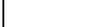
3.2. Functions of the application

The application was designed to provide two specialized functions. First, when a user chooses a colour that he or she determines is most similar to his or her skin or hair colour, the application recommends a matching colour. However, unlike other similar applications that merely offer colour chips of skin tone and hair colours, this application realistically shows

Table 1. The twelve personalized colour types of the PCDS

		Hair color		Light		Medium		Dark	
				4YR 3/6	4YR 3/4	4YR 2/3	4YR 3/4	3YR 2/4	10YR 2/3
Yellow	Light	6YR 8/4		Yellow Star	Yellow Sun				
	Medium	6YR 7/4		Yellow Moon			Yellow Sunset		
	Dark	7YR 7/4							
Complex	Light	4YR 8/3		White Star	White Sun				
	Medium	4YR 8/4		White Moon			White Sunset		
	Dark	5YR 7/4							
Pink	Light	2YR 8/4		Pink Star	Pink Sun				
	Medium	1YR 7/4		Pink Moon			Pink Sunset		
	Dark	1YR 6/4							

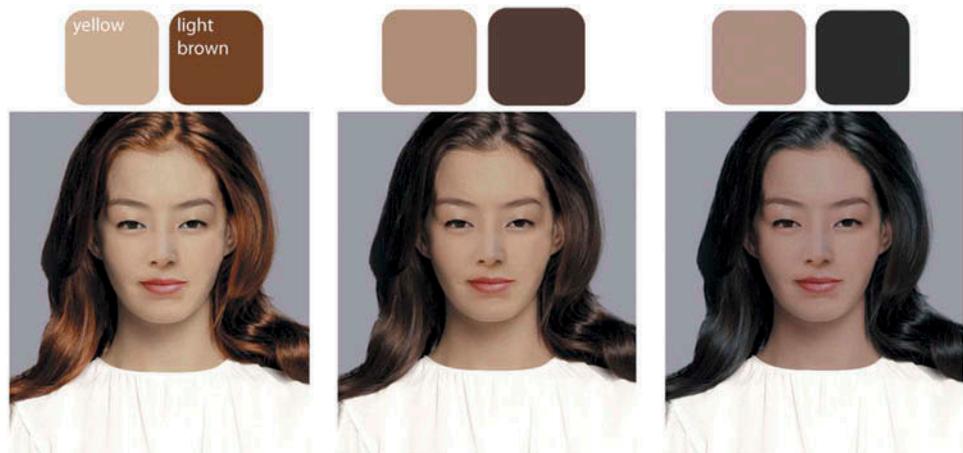
Table 2. Samples of converted colour values using the Munsell conversion program

Items		Color	HV/C	L*	a*	b*	R	G	B
Star	yellow star		4YR 5/8	71.3	7.7	15	208	174	163
			8R 4/13	57.6	31.8	27.5	210	123	109
			2YR 5/12	69.2	3.6	38.6	207	170	116
			8YR 6/10	73.2	-7.5	43.7	203	186	116
			2Y 7/10	74.5	-23.5	45.9	181	197	114
	white star		4GY 7/10	70.7	30.9	27.9	207	174	139
			3G 5/8	65.6	-7	-12.8	144	170	195
			10GY 5/10	57.6	-25.1	-15.9	60	159	179
			7PB 4/8	64.5	-39.4	30	113	179	118
			10G 5/7	77.5	-16.6	24.5	189	202	161
	pink star		5PB 3/10	10.9	-17.9	-4.7	143	188	195
			2RP 5/7	69.1	7.7	-4.7	189	170	191
			4RP 5/10	71.8	5.9	4.7	200	177	182
			1RP 4/8	6.73	11.5	12.7	202	162	157
			9RP 4/12	68.3	18.3	-2.3	206	161	185
			9P 3/8	69.1	7.7	-4.7	189	170	191
			6R 3/11	64.9	6.6	-13.1	169	161	194
			7R 4/7	63.7	17.2	-7	189	151	181

images of a human model with various skin tones and hair colours (Figure 3). The skin and hair colour are shown as square icons that the user can touch to make selections. The icons are 100 × 100 pixels, a suitable fit to an adult fingertip size, and, when a user touches an icon of a skin or hair colour, the sample image of the woman beneath that icon changes to match the chosen colour. Altogether, the possible combinations of nine skin tones and seven hair shades yield 63 sample images in the PCDS guidelines.

The second function of the application is its ability to photograph the user and identify her or his skin and hair colours and to automatically determine and present a match from the PCDS database. The results might vary according to the colouring of the photograph, and, therefore, it is important that the user snap a photograph with skin and hair colours as similar as possible to the user's actual colouring. To obtain a highly usable (accurate) photograph, the application page provides specific instructions for taking a photograph, with the user facing forward on a white background with ambient lighting. Moreover, the user could adjust the brightness and contrast of the photograph after it is taken to adjust the colours to be as precise as possible.

Figure 3. Images presented for choosing skin and hair colours.



Regarding skin colour, the average of the values of both cheeks and the jaw (from the photograph) is automatically calculated. The application calculates the difference between the L*a*b* value of the skin tone in the photograph and the L*a*b* value of the application’s pre-determined typical Korean skin tone. Then, it categorizes the skin colour based on the typical colours with the least extent of difference from the photographed skin colour. Equation (1), based on CIELAB, is used to calculate this colour difference (ΔE).

$$(\Delta E^*)^2 = (\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2 \tag{1}$$

For example, assuming that one of the values of the typical colours were L*a*b and the values of the skin tone with the three points in the photograph were $L_1^*a_1^*b_1^*$, $L_2^*a_2^*b_2^*$, and $L_3^*a_3^*b_3^*$, the colour difference would be as determined by Equation (2). Because a smaller colour difference indicates a closer colour match, the application was designed so that the skin colour with the smallest colour difference among the nine typical colours would be identified as the user’s skin colour. Hair colour extracted from the photograph is calculated using the same method as the calculation of the skin colour.

$$(\Delta E^*)^2 = \left(\frac{L_1^* + L_2^* + L_3^*}{3} - L^* \right)^2 + \left(\frac{a_1^* + a_2^* + a_3^*}{3} - a^* \right)^2 + \left(\frac{b_1^* + b_2^* + b_3^*}{3} - b^* \right)^2 \tag{2}$$

3.3. Categorization of personal colouring

In the PCDS, Star, Sun, Moon, and Sunset are the four personalized types of users based on their colouring, each of which has ten matching colours (for a total of 40 fabric colours). The application presents these 40 fabric colours on virtual tee shirts. Each of the ten colours per type is presented as a 100-pixel × 100-pixel square icon beneath that colour’s personalized type (Figure 4). Users touch the icons to change the colour of the tee shirt representing the personalized type. Also, the tee shirts can be moved to overlay a user’s photograph so that the user can compare the clothing colour to the face in the photograph.

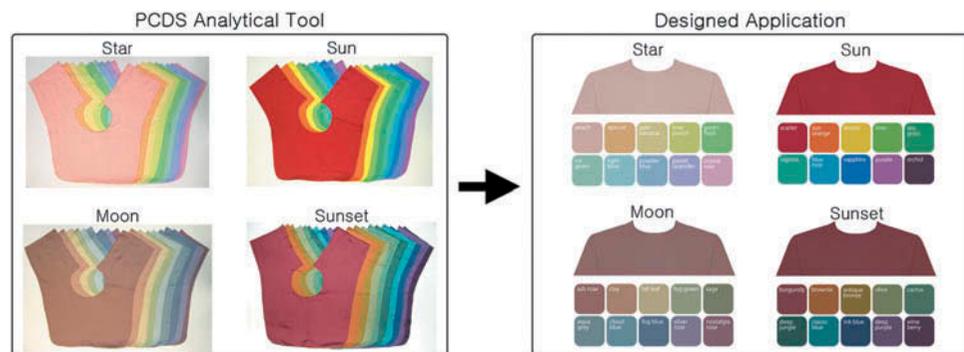
4. Results

4.1. Final design

The application was named “MY COLOR MY STYLE.” On the title bar of each page of the application are the identifying titles of the pages and icons that allow users to return to previous pages. The “home” icon is at the lower right corner of the screen to allow users to return to the first page.

The finalized PCDS application has two different functions. In the flow chart page, touching the Sample Photo icon takes users to Function 1 and touching the My Photo icon takes users to Function 2. In the Function 1, after the most similar colours among the colour chips of typical Korean skin and hair colours are selected, they are applied to a sample photo. Then, the application takes users to the result page. In the Function 2 page, the camera icon snaps the photographs, and the gallery icon retrieves the photographs. And the sliders were added for adjusting

Figure 4. Comparison of the PCDS analytical tool and the designed application.



the photo size to locate the forehead, cheeks, and chin inside the circles and adjusting brightness and contrast to create an image similar to the user’s skin and hair colours. Then, type categorization after the skin and hair colours are automatically computed.

The results of the analysis offer the six best colours by presenting one of 12 precise types. The user can then overlay a variety of coloured virtual tee shirts on his or her photograph according to the personalized type (Star, Sun, Moon, and Sunset). In this way, the user can also see the other colours in the same category. Finally, the application presents specific fashion styles for each personalized type, so it helps users to choose clothes (Figure 5).

4.2. Usability evaluation

For examining the usability of the application, a workshop was conducted for twenty-seven university students aged 20 to 25 from Yonsei University, in which they used the application and participated in a survey to evaluate it. The participants rated the application on eight criteria—convenience, entertainment, reliability, satisfaction, design, colour implementation icon size and font size using a scale of 1 (strongly unsatisfied) to 5 (strongly satisfied) (Figure 6). Average ratings were at least three points on most of the criteria. In particular, convenience (92.5%), entertainment (96.2%), suitability of font size (96.2%), suitability of icon size (81.4%), and colour implementation (81.4%) were rated three or more points. This result indicates that the application achieved its purpose as a fun, convenient, and accurate smartphone PCDS application.

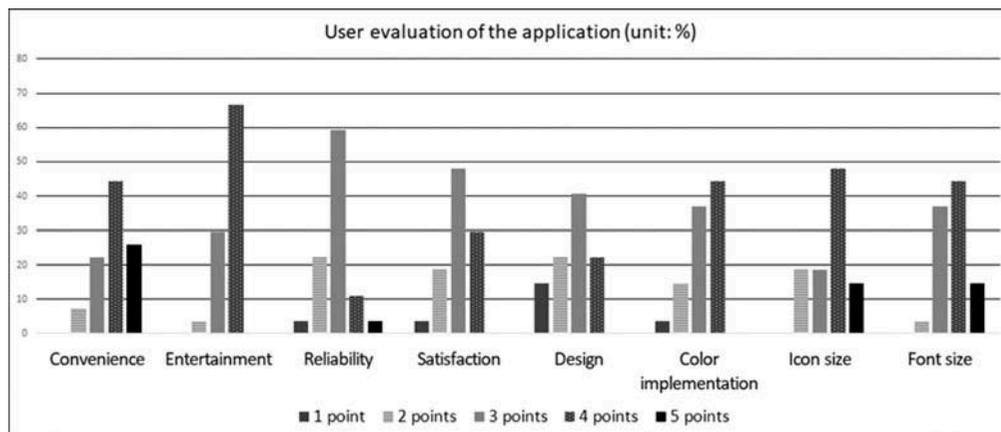
To examine the accuracy and satisfaction of the mobile application, we compared the colour analysis results from the mobile application to the results from the fabric analysis method. We recruited thirty women—aged 25 to 35 years who are interested in analysing the colours of clothes that harmonize with skin and hair colours for fashion styling or image consulting—through advertisements placed in social media. The participants were analysed by experts first, and then they tested the application by themselves. After examinations, we conducted surveys and interviews. The surveys were evaluated in the dimensions of convenience, entertainment, reliability, and overall satisfaction and used a 5-point Likert scale ranging from 1 (strongly disagree) to 5 (strongly agree).

First, snowball sampling was conducted to recruit personal colour analysis experts. There were three personal colour analysis experts: (1) a personal image consultant with a Master’s degree in

Figure 5. Flow chart of the application’s final design and functions.



Figure 6. Evaluation results.



Fashion Design and five years' experience in personal styling and image consulting, (2) a PhD candidate with a Master's degree in Fashion Design and over ten years cosmetic and make-up industry experience, (3) a professor in department of clothing and textiles and over fifteen years' clothing and colour research experience, that analysed thirty women's personal colour type harmonized their skin and hair colours following the original PCDS procedure.

Secondly, the women got informed about the mobile application usage and asked to use it by themselves. They took their pictures following guide on the application screen and got their personal colour type classified automatically.

The results found that the colour experts' and mobile app's analyses were consistent on 93% (28/30 women) of the results. Thus, the results using the application were highly accurate compared to the analyses of the colour experts. From the results of the survey, we found significant differences in the dimensions of convenience, entertainment, and overall satisfaction. Convenience (mobile app average score 3.9, SD 0.91 vs original PCDS average 2.3, SD 0.81), entertainment (average 4.1, SD 1.08 vs 3.3, SD 0.92), and overall satisfaction of mobile app was higher than original PCDS methods (average 4.1, SD 0.93 vs 3.3 SD 0.82), with 87% (26/30 women) stating that they would continue to use the mobile app. However, only 53% of the participants would continue to use the fabric analysis method. From the interview, they mentioned that the original PCDS method spent too much time. And it seemed outdated and annoying to wear the fabrics on their shoulder. However, they think the mobile app looks fancy, fun and easy to use.

5. Discussion and conclusions

Studies on identifying the colours that best match individuals' natural colouring have been conducted continually since the 1960s. Personal colour analysis systems provide shade (hue), value, and chroma that harmonize with the personal colouring using an analytical framework that applies changes to clothing colours as a variable. However, most of the personal colour systems still require expert analysis with complexities. Thus, the process is time-consuming and costly for individuals. Because the analytical results of the systems depend on expert opinions that might vary, the recommendations of colours might be raising doubts about accuracy and effectiveness, and consistent.

This study developed a mobile application that reduces costs and time consuming and overcomes the shortcomings of the Personal Color Analysis System by enabling non-experts to analyse their personalized colours easily and accurately. The colour experts' method of placing diagnostic coloured fabrics on subjects' shoulders has to pass through at least four stages. In this mobile application, all the stages are replaced by automatic calculating and categorizing a user's skin tone and hair colour identified from the user's photograph. Furthermore, a virtual packet of fabric

colours replaces the previously used physical swatches to identify the colours that best match a user's skin and hair colours, which are visualized as virtual tee shirts that can be overlaid on the user's photograph so that the user can easily self-analyse his or her personal colours without requiring colour experts. The results of the usability evaluation found that the application was easy, fun, and accurate. Again, the application emphasizes the importance of colours that match users' skin and hair colours and provides baseline data for future research on clothing colours that considers more than comparisons among shades by also using value and chroma.

However, the application developed by this study cannot produce accurate results unless the user's photograph displays precise skin tone and hair colour because the colour analysis depends on the photograph's accuracy. The application is guiding the proper way to take a photo by inside manual, but the application could be somewhat limited in that the results might vary depending on the user's skill. Furthermore, because the analytical results are based on Asians' skin and hair colours, the application could be useful for Asian. But the application is very easy to extend the ranges of skin and hair colours as adding the numerical values of skin and hair colours. Thus, future studies should improve the application by adding skin and hair colour samples for people of other racial and ethnic backgrounds to extend its use to other countries.

This study aimed to increase the usability of the Personal Color Analysis System by adapting its technology from the personal colour analytical method that uses fabrics and experts to the mobile phone application. This study is expected to establish a framework to advance research on clothing colours by enabling non-experts to analyse their personal colouring easily, and also expected to assist consumers in choosing clothing colours substantially.

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None

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