An evaluative study on perceived colour measurement method in architecture using tablet devices

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When we think of colour experience in architecture, the judgement of perceived colour, which is affected by the human perceptual system, is critically important because the goal of architectural design is to construct the human-centric environment. However, recording observers' judgement of the perceived colour is not always easy in field surveys. Recently, several methods have been developed to measure perceived colour. In this study we propose to use portable tablet devices in consideration of its easiness to carry and use in the actual architectural field survey. The validity of the method using portable tablet devices to judge perceived colour is verified by comparing its performance with that of the conventional colour matching method, with the help of colour charts. Experimental results show that the proposed method has sufficient validity for the judgement of perceived colour in spaces under sufficient light by matching the correlated colour temperature on the tablet display to that of the surrounding light.

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Introduction

Colour in architectural design and research can generally be measured or judged in three different ways, as shown in Figure 1. The first method is the measurement method of psychophysical colour, whose tristimulus values can be measured in a contact state using a reflectance spectrophotometer or colorimeter (hereafter referred to as 'Psychophysical colour' in this paper). The second method is the measurement way of the colour under actual lighting in architecture, where non-contact surface colour measurements are made using luminance and colour meters like KONICA MINOLTA CS-100 (hereafter referred to as 'Colour under actual lighting'). The third method is the judgement of perceived colour in real architecture, which is affected by the human perception system, such as light adaptation and colour contrast (hereafter referred to as 'Perceived colour').

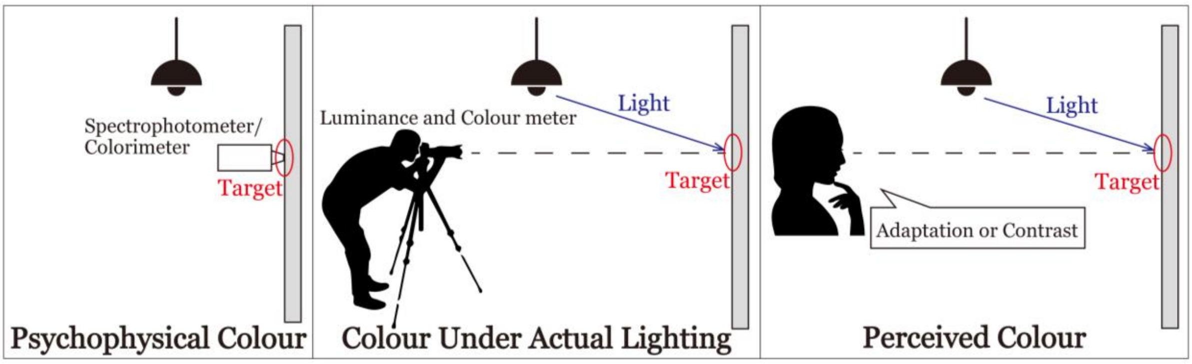


Figure 1: Three types of colour measurement.

Colour constancy is a phenomenon in which object colour perception is stable under changes in illuminant chromaticity. If the colour constancy is accurate, the perceived colour can be determined only by the colour contrast among objects in the space, and it will not be affected by illumination. However, it is well known that the human colour constancy is seldom robust, and even if observers take enough time to adapt to the lighting in their environment, their perceived colour of a target does not match its psychophysical colour and takes on various appearances under variable illumination, as Arend referred to these phenomena using the term 'apparent surface colour' [1]. Although this type of colour is actually important and fundamental to understanding the value and meaning of the colours in architecture, it is sometimes difficult to capture observers' judgement of the perceived colour in an architectural field survey.

Several methods have been proposed to describe the perceived colours, and one of which is the colour naming method. If it can be assumed that the sense of colour indicated by the colour name matches among different people, the colour can be quantitatively treated by its colour name. Berlin showed that there are 11 basic colour categories of perceived colour that are universal for humankind [2]. Boynton reported that the range covered by each colour name matched to some extent among different languages [3]. Based on these colour-naming methods, the elemental colour scaling method was developed to enable the quantitative measurement of colours. The generic technique of hue and saturation scaling was first described by Jameson [4], and Gordon established an elemental colour scaling method in which a measurer answered the proportion of the hue and saturation of red, yellow, green, or blue [5,6]. Fuld added black and white as basic colours, and in his revised method, measurers assigned the percentages to the names blue, green, yellow, red, brown, black, and white, which represented the proportion of these colours seen in the target [7]. There is considerable evidence that differences in language have little effect on the meanings of the unique hue terms [3], and Gordon showed that there were no systematic differences in the variance between-subjects in the hue scaling task [6]. However, the choice of hue categories is usually arbitrary. In addition, many subjects reported in Gordon's experiments that it was difficult to judge saturations [6]. It is possible that this method is too subjective to judge colour.

Another commonly used method for measuring perceived colours is a colour matching method in which reference colour chips are used [8]. In contrast to the object colour measurement method in which colour chips are placed next to the target as a reference and illuminated by the actual surrounding lighting, the colour chips are observed under a standard illuminant, and observers compare the target colour with the colour chips to specify its appearance. The advantage of this method is that it is relatively easy even for the observers without the knowledge of colour theory, however, since it requires the use of a device that can cut the surrounding light around the colour chips and illuminate them by using a standard illuminant, this measurement method is sometimes difficult and impractical.

Perceived colour must be judged from a distance, and, recently, many methods have been developed that use digital devices as a colour measurement method for distant targets. Earlier, images were captured on a digital camera, and the colour of each pixel of the image taken in the field using digital cameras is extracted as three stimulus values [9]. This method is used to measure 'colour under actual lighting'. The more recent methods use a combination of images taken using digital devices and calculations. They are focused predicting the colour of the surrounding light from an image and measuring the 'psychophysical colour' of an object. A considerable number of studies have been conducted on the spectral reflectance estimation in various research fields [10-11].

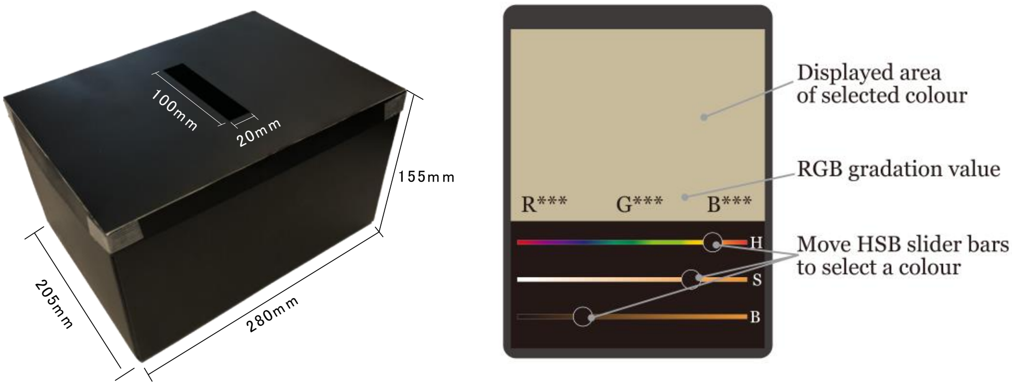
If we measure 'perceived colour' using images taken on digital cameras or tablet devices such as smartphones, the human perception system must be completely elucidated. Instead of that, in the perceived colour measurement, images captured by digital devices could be used as reference for colours [12-13]. We attempted to use portable tablet devices instead of the usual paper-made reference colour charts, because a tablet device can be easily treated in small steps and is easy to carry in the actual architectural field survey. There are several concerns regarding the display of colours on tablet screens. One is that the colour appearance of a tablet display differs depending on the ambient lighting condition [14], therefore, we covered the tablet device by a black box to cut the surrounding light, and the observers have to see the tablet's screen through a small opening. The other is that the matched colours between different devices, such as paper charts and CRT / LC displays, does not necessarily have identical tristimulus values because of the metamerism problem [15]. Oicherman reported the colour matching results among computer displays and paint samples and proposed a framework to explain these discrepancies [16-17].

In order to use this measurement method with tablet devices in real architectural field survey, the reliability should be assured beforehand. It can be said to be unsuitable if the result differs significantly from observer to observer. We verified the validity of this method using tablet devices to grasp the perceived colour under various illumination through a subjective experiment. Experiments were conducted using a trusted conventional surface colour measurement method [18] to compare the differences among individuals. If the differences among the individuals using the tablet devices are the same as those using the conventional surface colour measurement method, this tablet device-based method can be actually used in architectural colour survey.

Method

The tablet device (Apple iPad Pro 10.5-inch) was covered with a black box to cut the surrounding light, and the observers saw the device's screen through a small opening (see Figure 2a).

Colour chart software (flat palette; Tokyo Cartographic CO., LTD.) was used, and an observer moved hue, saturation, brightness (HSB) slider bars and singled out the colour on the tablet, which was judged to be the same as the perceived colour on the target (see Figure 2b). Theoretically, more than 16 million different colours can be chosen using this method. All operations were performed using a touch pen to reach the screen from the small opening and to avoid fingerprints on the screen. After the experiment, the spectral distribution of the selected colours on the screen was measured using a spectroradiometer (KONIKA MINOLTA CS-2000) in a laboratory.



(a) *(b)*

Figure 2: (left) Black box and (right) Colour chart software on display.

Experiments

In this research, the differences among individuals in terms of the colour matching results obtained using the proposed method (hereafter referred to as 'tablet method') were compared to the those obtained using surface colour measurement method, prescribed in ISO/DIS 3668, in which colour chips are placed next to the target as a reference (referred to as 'conventional method').

Figure 3 shows the section and plan of the experimental room and the target and background for both methods. The experimental dark room was 3000 mm long, 3000 mm wide, and 2400 mm high, and all the walls, floor, and ceiling were painted with N9.5. The target to be evaluated was placed on a wall and illuminated by a spotlight from a 45-degree angle. Using the tablet method, observers evaluated the target from a distance of 500 mm, and an 87 mm square colour chip, which subtended 10° on the observers' eye, was presented as an evaluation colour on a 257 mm square background surface. In the conventional method, observers evaluated the target from the same distance, and an 18 mm square colour chip subtending 2° was presented on the background.

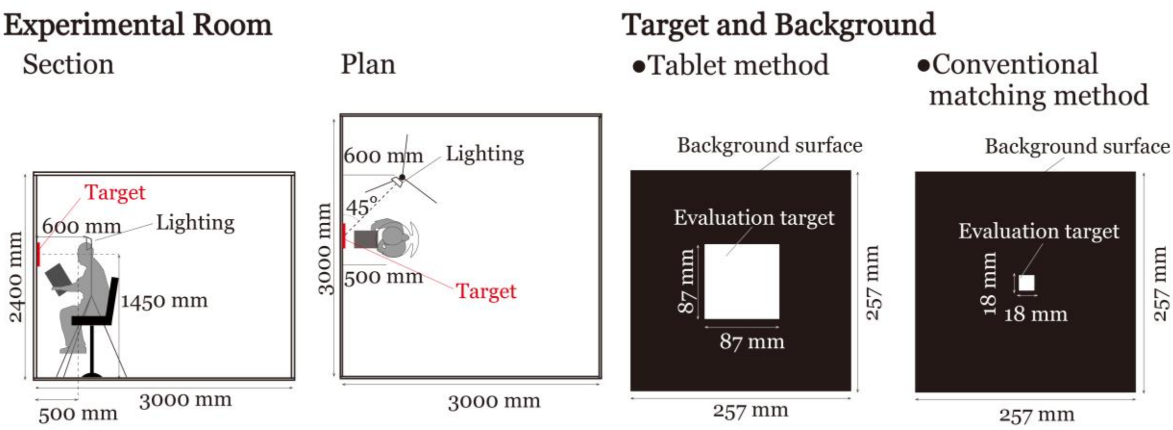


Figure 3: (left) Experimental room and (right) Target and Background in both methods.

The experimental factors were (1) target colour, (2) background colour, (3) correlated colour temperature (CCT) of incident light when evaluating the target, (4) illuminance on the target, (5) CCT of incident light when entering the experimental room, and (6) CCT of the display and the colour of the display when starting the experiment. As shown in Table 1 (upper), (1) evaluation targets were made of matte paper with N9.5, N7, 8YR9/2, and 9PB7.5/3. The final goal of our study is to develop a method for measuring perceived colour in white architecture. Therefore, in these four years, we measured the actual colour of more than 50 buildings, we selected four colours to cover the range of the measurement results, that is, N9.5 and N7 as achromatic colours with different brightness, 8YR9/2 as yellow-tinged white, and 9PB7.5/3.0 as blue-tinged white. (2) The background surface colour had four levels; N5, 5B4/5, 3GY5.5/5.5, and 10R5/6.5. Background colours were used to compare the effects of colour contrast. These four colours were selected as usual surroundings in real architecture. For example, 5B4/5 (blue) is for the sky, 3GY5.5/5.5 (green) is for trees and plants, and 10R5/6.5 (brown) is for the ground. (3) CCT of incident light when evaluating the target was 6500 K (SERIC SOLAX-iO LE-9ND65: Artificial Solar Lighting) and 3000 K (Panasonic Dichro-cool halogen JDR110V30WKM/5E11-H). (4) Illuminances on the target were 1000 lux and 50 lux, where a stainless wire mesh was used to reduce light to ensure that the CCT does not change.

In the experiments conducted using the tablet method, the following factors were also added. (5) When entering the experimental room, the CCT of light was set to be 6500 K or 3000 K using the same luminaires mentioned above, and the illuminance on the wall where a target would be placed was kept at 1000 lux. (6) At the beginning of the experiment, the display of the tablet device was set to be 'white with 6500 K', 'white with 3000 K' or 'Black'. Factors (5) and (6) were blocking factors, and Table 1 (bottom) shows the indicators of the experimental blocks.

(1) Target Colour	N9.5	N7	8YR9/2	9PB7.5/3
(2) Background Colour	N5	5B4/5*	3GY5.5/5.5*	10R5/6.5*
(3) CCT when evaluating the target	6500 K	3000 K		
(4) Illuminances on the target	1000 lux	50 lux		
(5) CCT when entering the room	6500 K	3000 K **		
(6) Display CCT - Display colour when starting	6500 K - White **	Black **	3000 K - White **	

* Only for the Tablet Methohd 1-A Experiment ** Only for the Tablet Method Experiments

Tablet Method Experiment	CCT when entering the room	Display CCT - Display colour when starting
1-A	6500 K	6500 K - White
1-B	6500 K	Black
1-C	6500 K	3000 K - White
2-A	3000 K	6500 K - White
2-B	3000 K	Black
2-C	3000 K	3000K - White

Table 1: (upper) Factors and levels and (bottom) Experimental Indicators by blocking factors in the Tablet method.

In 1-A (tablet method), 23 observers evaluated the colour of the four targets on the four background colours, whereas in 1-B, 1-C, 2-A, 2-B, and 2-C (tablet methods), 19 observers evaluated four targets on the sole background whose colour was N5. In the experiments conducted using the conventional method, the CCT of light when entering the room was set to be constant at 6500 K, and 23 observers evaluated four targets on the sole background N5. All observers were in their early 20's with normal colour vision, and 14 observers of them evaluated all the conditions.

An observer entered the experimental room and was seated at the evaluation point. It took 10 min for the observer to adapt to the light environment in which the CCT of light was set to be 6500 K or 3000 K. Next, it took 2 min for the observer to adapt to the lighting, to evaluate a target. The experimenter set the target and its surrounding conditions, and then the observer evaluated the colour of the target after observing it for 20 s for adaptation. The evaluations done using the tablet and conventional methods were performed on different days, and half of the observers began the experiments using the tablet method. The experimental runs were randomised for every blocking factor.

Discussion

The results were analysed on the CIE 1976 u'v' [19] as shown in Figure 4 on Experiment 1-A. There were three tendencies in the individual evaluations. Figure 4 (a) shows the result of observer 1, whose evaluation of ‘Perceived colour’ was really close to ‘Colour under the actual lighting’. Figure 4 (b) is for observer 2 who evaluated the ‘Perceived colour’ close to the ‘Psychophysical colour’. Observer 3 in Figure 4 (c) was similar to observer 1, but had no clear tendency. The majority of the subjects valuated the colour like observer 1 and observer 3, and only two subjects fell into the category of observer 2. Because there was a concern that these subjects misunderstood the experimental instruction and tried to answer ‘Psychophysical colour’ instead of ‘Perceived colour’ itself, their results were excluded from the following analyses.

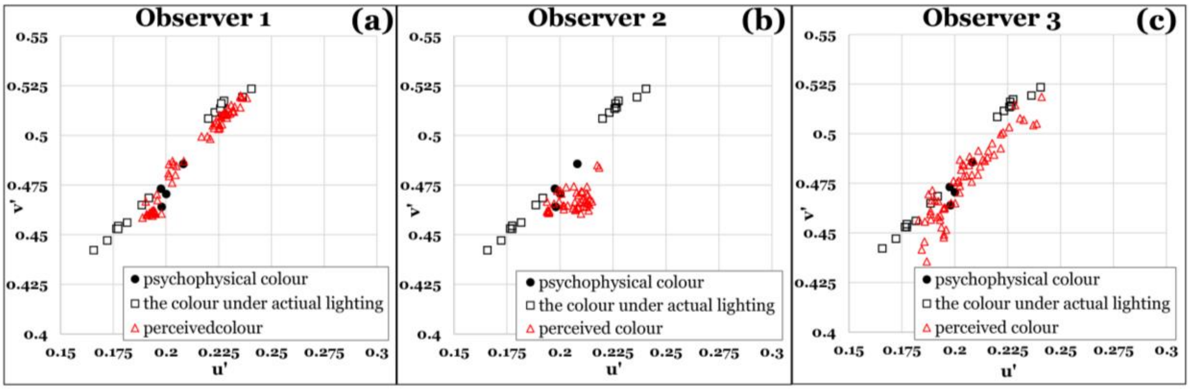


Figure 4: Three types of individual evaluation on Experiment 1-A.

As shown in Figures 5 and 6, differences among individuals were compared based on the distances among the points of evaluated values described in CIE 1976 u'v', instead of CIE DE2000 colour-difference formula [20], since the tablet screen presented light source colour. All the distances among the observers’ evaluations under each condition were calculated, and the boxplots with their maximum, upper quartile, median, lower quartile, and minimum values are presented in the graphs. When the average value is close to 0, it indicates that the difference in evaluation among observers is small. The results of the conventional method are shown in pink in Figure 6.

Graphs 1-4 in Figure 5 show the results of the experiment 1-A, that CCT when entering the room was 6500 K, and the display of the tablet device was set to be ‘white with 6500 K’ at the beginning of the experiment.

As shown in graphs 1 and 2, under the condition of 3000 K, the difference among individuals did not different by the background colour, regardless of illuminance (test for homogeneity of variance in the case of CCT when evaluating the target 3000 K and illuminances on the target 1000 lux: Bartlett test, P=0.2353) (test for homogeneity of variance in the case of CCT when evaluating the target 3000 K and illuminances on the target 50 lux: Bartlett test P<0.05). However, under the conditions of 6500 K shown in graphs 3 and 4, the difference among individuals was evident depending on the illuminance, although the influence of the background colour was not seen(test for homogeneity of variance in the case of CCT when evaluating the target 6500 K and illuminances on the target 1000 lux: Bartlett test, P<0.0001) (test for homogeneity of variance in the case of CCT when evaluating the target 6500 K and illuminances on the target 50 lux: Bartlett test P<0.0001). Therefore, since there is no difference in the influence of the colour contrast in the perception of target colour regardless of illuminance and correlated colour temperature, it seems that there is no big problem in using tablet devices for the measurement of the perceived colour in the real space consisting of multiple colours.

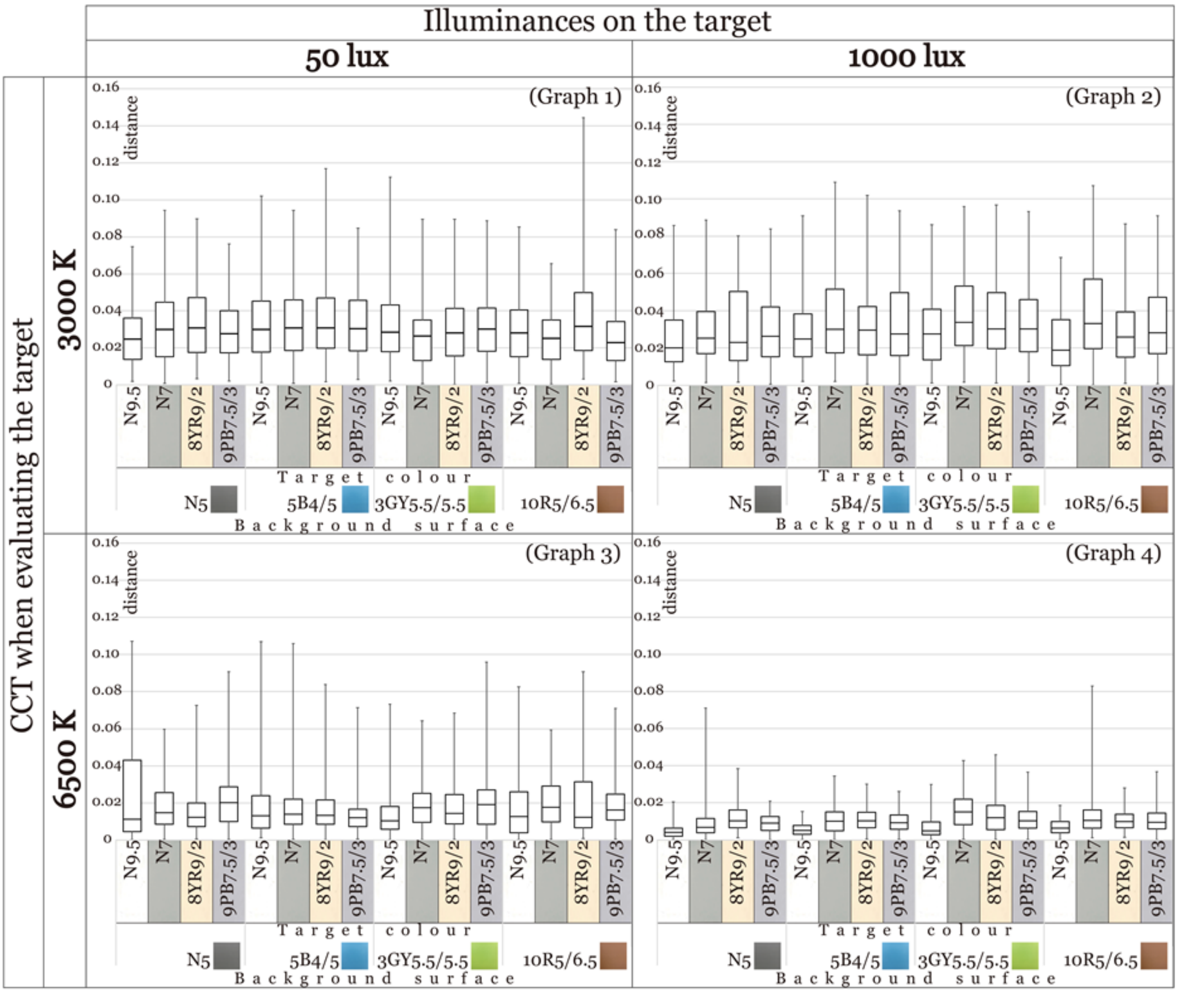


Figure 5: Differences among individuals of colour evaluation on Experiment 1-A.

Graphs 5-8 in Figure 6 show the results for the target colour N9.5, for all the conditions. As shown in Graph 6, under the condition of 1000 lux, the difference among individuals was small in the combination; that in the beginning of experiment, the target, and the tablet display were all set to 3000 K. As shown in Graph 8, similar results were also seen observed in a combination of 6500 K. It was observed that differences among individuals by the tablet method were reduced and nearly the same as the conventional one when CCT of incident light when evaluating the target, CCT when entering the room, and CCT setting on the display at the beginning of the experiment were all the same, only if the target illuminance was 1000 lux. Although there was no statistical homoscedasticity, the difference among individuals at the conditions that the beginning of the experiment, the target, and the tablet was set to the same correlated colour temperature, and was found to be smaller than that in different conditions(test for homogeneity of variance in the case of CCT when evaluating the target 6500 K and illuminances on the target 1000 lux, the conventional method and the Experiment 1-A of the tablet method: Bartlett test, P<0.0001) (test for homogeneity of variance in the case of CCT when evaluating the target 3000 K and illuminances on the target 1000 lux, the conventional method and the Experiment 2-C of the tablet method: Bartlett test, P<0.0001). As shown in Graphs 5 and 7, the differences among individual differences were relatively large under any combinations of tablet/room CCT in a dark environment such as 50 lux.

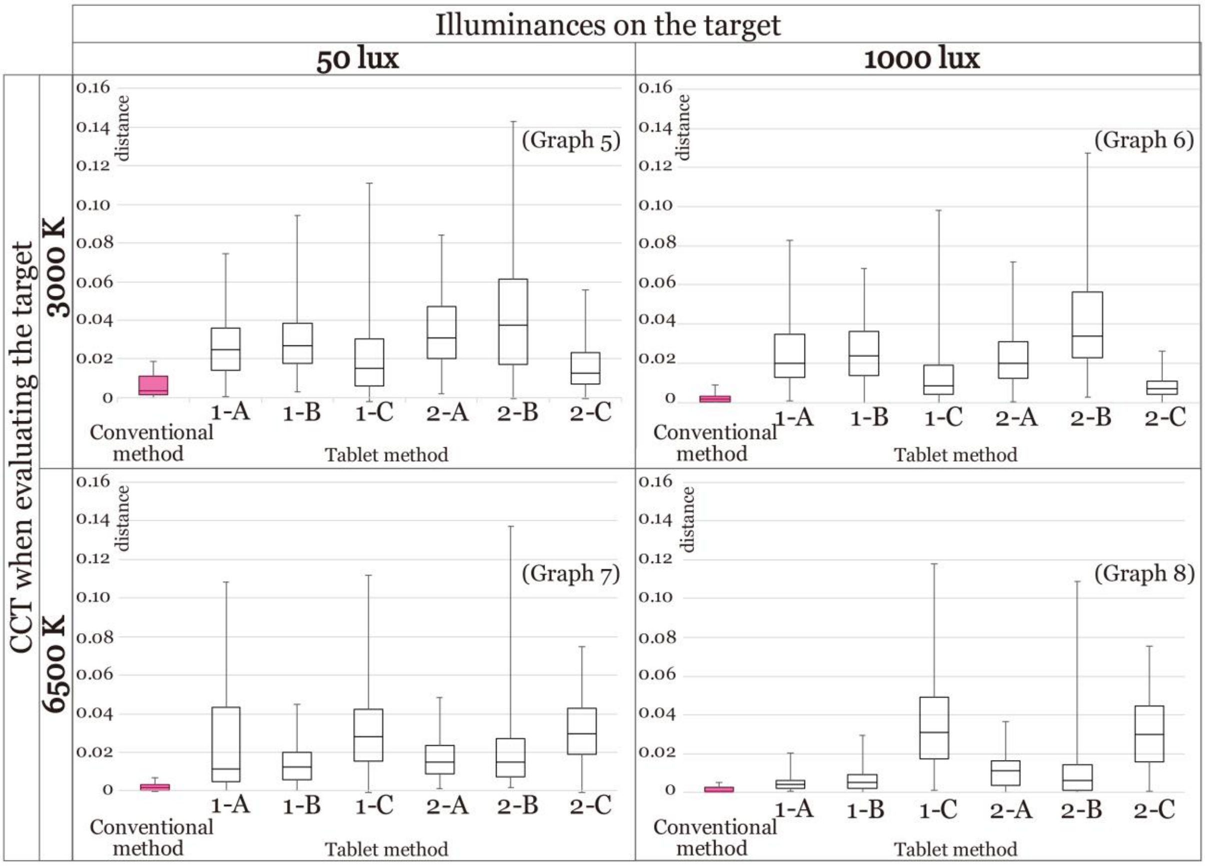


Figure 6: Differences among individuals of colour evaluation under each condition, Experimental results of the target colour N9.5 on background surfaces N5.

Conclusions

Through the above experiments, the validity of the colour measurement method using a tablet device, which could be measured by equivalent individual difference as the conventional method using paper colour charts, was verified. Under the condition that the target colour was sufficiently illuminated at approximately 1000 lux, detailed changes in perceived colour could be evaluated using the reference colour scale displayed on the tablet screen.

These results indicate that the lighting setting just before the start of the evaluation had an effect on the colour evaluation by this method using a tablet device. It can be assumed that the memory colour of the target under the luminous environment before the start of the evaluation would affect the colour judgement. In a dark environment, such as 50 lux on the target, this method could not be applied. In actual measurements in the field study using this method, it is desirable to measure the perceived colour in architecture under sufficient light by first matching the CCT on the tablet display to that of the surrounding light.

This research clarified the conditions in which tablet device-based method can be applied, however, the metamerism problem between different devices still remains. In future work, we will investigate a method to measure the perceived colour in architecture in a dark environment and also clarify the intra-individual differences by this method using a tablet device.

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