• Clinical Research •

Red tinted contact lenses on Ishihara test error scores in color deficient subjects: a pilot study

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Abstract

● **AIM:** To compare the Ishihara test errors scores of colour vision deficiency (CVD) subjects when wearing four different types of red-tinted contact lenses (RCL) that differ in their transmittance as determined using a spectrophotometer.

● **METHODS:** Six congenital CVD subjects volunteered to participate in this study. Ishihara plates were used to determine the colour vision errors made, whereas Farnsworth-Munsell 100 Hue test was conducted to determine the total error scores (TES) and type of CVD. Four types of RCL (Types A, B, C and D) were inserted in the non-dominant eye and tested in a randomised manner by a masked operator. Errors scores in Ishihara test were determined at baseline without any contact lens and after wearing the four different RCL. The subjects were then divided into two groups based on the mean TES.

● **RESULTS:** Repeated measures ANOVA with Greenhouse-Geisser corrections showed that there was a highly significant effect of RCL type on Ishihara error score [$F(2.056, 10.282)=30.214$, $P<0.001$]. Error scores with RCL Type B were significantly lower than errors made when no lens was worn, and with RCL Type C and Type D (all $P<0.001$). Error scores with RCL Type B were also lower than those made with RCL Type A, however, they were not significantly different. For subjects with TES values less than 180, RCL type B showed the largest improvement in Ishihara error score (50%) compared to the other three RCLs. RCL type A showed the best performance in TES value of more than 180, with an improvement of 80% in Ishihara score. RCL Type A has the lowest transmittance at the confusion wavelength (450-568 nm), followed by RCL Types B, D and C.

● **CONCLUSION:** This study shows that RCL can improve Ishihara error scores. RCL with lower transmission at 450-568 nm and 90% transmittance beyond 637 nm are the most effective. Lenses which could block more light between 550-580 nm are more effective for colour defectives with more severe colour defects.

● **KEYWORDS:** anomalous trichromats; colour vision deficiency; contact lenses; deutan; protan

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INTRODUCTION

Colour vision is important in our daily lives as it provides important sensory information about the environment. People with normal colour vision can differentiate colours due to the presence of 3 cone types, that are, long wavelength sensitive (L) cones, medium wavelength sensitive (M) cones and short wavelength sensitive (S) cones. The L cones, M cones and S cones have pigments within them which are wavelength specific. Colour vision deficiency (CVD) is a condition when there is reduced ability to distinguish between certain colours. It is due to an absence or dysfunction of one or more of the three cone cells resulting in various types of CVD[1]. CVD is categorised as anomalous trichromacy, dichromacy and monochromacy.

Anomalous trichromacy is the mildest form and anomalous trichromats have all three cones present in the retina. However, one of the cones has an altered pigment. An altered pigment in the L cones, M cones and S cones result in protanomaly, deuteranomaly and tritanomaly respectively. Dichromacy is a severe CVD. There is a complete loss of function in one of the three cones. Complete absence of L cones, M cones and S cones results in protanopia, deuteranopia and tritanopia respectively. Monochromacy is a total CVD whereby there are no cones present in the retina, which results in complete loss of colour perception.

CVD develops because of hereditary (congenital) or acquired factors. Congenital CVD is an inherited condition and is usually exhibited as a red-green colour defect. It is caused by a common X-linked recessive gene, which is passed from mother to son. This is evident when comparing the prevalence of colour deficiency in male and female. According to Boyce-Bain[2], congenital colour deficiency affects 1.50%-4.60% of males and 0.10%-0.80% of females in the global population. A study demonstrated that all red-green deficiencies present less sensitivity to detect red light compared to a normal trichromat[3]. The protanopes are the most disadvantaged because they lack L cone-pigment which reduces their ability to differentiate red, green and yellow, and also the ends of the visible spectrum appear less luminous.

Without normal colour perception, humans will face many challenges in life, impacting their quality of life. A previous study has shown that 90% of dichromats and 66% of anomalous trichromats had difficulties in their daily activities related to their CVD[4]. They will face difficulty in determining the traffic light signals, reading maps, distinguishing the ripeness of fruit, distinguishing the colour codes designed for safety purposes and index labels, identifying matching clothing, enjoying various forms of entertainment, as well as, limitations in the selection of critical occupation such as in the police force, military, pilots, commercial drivers and many more[5-7].

Currently, there is no treatment for CVD condition. However, many researchers are innovating colour vision aids to help the colour deficient subjects in improving their quality of life. There are many types of aids available in the market such as tinted eyeglasses, specially tinted contact lenses and opto-electronic glasses[8]. Most of these aids use the concept of a red filter to enhance colour perception. This is because a red filter can increase the transmission of long wavelengths by absorbing the short and medium wavelengths. Therefore, the differentiation between red and green colour can be appreciated[9]. Diaconu *et al*[3] also reported an increase in the perception of red colour which was in line with the loss of green and yellow colour perception when red filters were used on protan subjects.

There are some studies on the effectiveness of these aids for CVD subjects[8]. A study using Enchroma spectacle lenses was conducted on 48 colour defective subjects. These lenses were found to only enhance the colour perception of 5% and 9% of colour defectives when they performed Ishihara and Farnsworth-Munsell 100 Hue (FM 100 Hue) tests respectively[10]. VINO spectacle lenses were used in another study in which 52 colour vision defectives were tested by performing the Ishihara test and FM 100 Hue test. The study showed that the colour defectives recorded better scores on the Ishihara test than on the FM 100 Hue test[11]. Tinted contact lenses have also been used to compensate for the CVD. X-Chrome contact lenses were reported to significantly improve the performance of colour defectives on the Ishihara test[12]. ChromaGen contact lenses were worn by 14 colour defectives and were found to have significantly reduced errors when performing the Ishihara test[13]. A study by Elsherif *et al*[14] compared performance on the Ishihara test of deuteranomaly and deuteranopia colour defectives while wearing commercial glasses (Enchroma, Pilestone TP-025, Pilesotne TP-012, HB-585-BL and their own Atto contact lenses 565 and Atto contact lenses 488). In the case of deuteranomaly subjects, the most effective glasses were the HB-585-BL, which showed a 53% increase in plates perceived, followed by Pilestone TP-012 with a 33% increase. Pilestone TP-025, DLC, and Atto 565 samples showed similar performance presenting an increase in performance of 21%. Enchroma glasses and Atto 488 were the least effective. A similar trend was observed for deuteranopia subjects but with half the percentage increase. In the study by Elsherif *et al*[14], they also asked patients to provide their lens wearing experience when viewing the environment outdoors. The general comment, however, was that with these glasses on, the contrast was reduced with everything appearing red. The colour deficient individuals were unable to differentiate between shades of green and red. All the colour deficient individuals described wearing these glasses as unpleasant.

Different colour vision filters show different results on colour deficient subjects. This reflects the significant need to optimize the lenses for each CVD individual. The difference in results in studies could likely be due to the method of producing the red colour tone during the manufacturing process of red-tinted contact lenses (RCL). Some lenses use dyes, and some have dot matrix prints. Comparing them may not produce the same outcome. Thus, there is a need to ensure that the tools used have a consistent colour tone and transmittance values to ensure that any change in colour discrimination is not due to any defects or inconsistencies in the colour vision aids. The Ishihara test is the most common screening test used to detect red-green congenital CVD. The easiest way to see if the red-tinted lens may benefit colour deficient individuals would be by testing with the Ishihara test. Tinting using dyes can absorb narrow ranges of wavelength. It can be customised with low cost and ease of production.

Therefore, this pilot study was conducted to compare the Ishihara test error scores of CVD subjects wearing four different types of RCL. The four different red colour tones led to differences in their visible wavelength transmittance, specifically for those longer than 560 nm, to determine which of them would minimize the Ishihara test error scores the most, compared to when no lenses were worn.

PARTICIPANTS AND METHODS

Ethics Approval This study was approved by the Research Ethics Committee of Universiti Kebangsaan Malaysia and Clinical Trial Registration Center of Universiti Kebangsaan Malaysia (approval number UKM PPI/111/8/JEP-2021-145; Clinical Trial Registration Number NCT05643222). The study procedures were conducted according to the tenets of the Declaration of Helsinki. All subjects were adults and had provided written informed consent before the start of the study.

Participants Six congenital colour deficiency volunteers aged between 22 to 28 years old participated in this pilot study which was carried out from 2 May 2021 to 15 May 2021. The inclusion criteria were age below 35y, had congenital CVD and being free from any ocular or systemic diseases. The exclusion criteria were contraindications for wearing contact lenses and not providing written consent to participate in this study.

Sample Size Calculation Since this is a pilot study, a small sample size of six subjects with CVD who volunteered were recruited. Some studies have used a small size in this type of research[12-13,15]. Subjects were recruited from the database of 40 subjects in the Optometry Clinic, Universiti Kebangsaan Malaysia.

Instruments

Ishihara test plates Ishihara plates test were used to screen for congenital CVD. It is a good screening tool with high sensitivity for assessing red-green colour deficiency[16], but it cannot diagnose CVD[17]. This study used the 38-plate Edition (Kanehara & Co., Ltd 1999, Japan) test. The test plates have numbers on a background, and the visibility of the numbers will depend on the viewer's colour vision. Subjects need to read the numbers or trace the path seen on each plate.

Farnsworth-Munsell 100 Hue test FM 100 Hue test was used to classify the type of CVD. This test consists of four boxes containing 85 removable colour reference caps spanning the visible spectrum. There are 22 caps in box 1 and 21 caps in each of the remaining three boxes. Among the sorting tests, the FM 100 Hue test is the most sensitive and widely used by clinicians[18]. Subjects were asked to arrange a set of individual-coloured caps of similar lightness and saturation in order, between the hues of two fixed caps, so that a smooth colour transition is formed, with the hue difference between neighbouring caps as small as possible.

Red-tinted Contact Lenses Four different types of soft, RCL (labelled as Types A, B, C and D) which varied in their red colour tone were used. These lenses are available commercially and all are dye tinted. The poly-HEMA RCL labelled as Types A, C and D had a water content of 38% while Type B had a water content of 57%. The spectral transmittance of all the contact lenses was measured using a spectrophotometer (PRIM Light Model, SECOMAM®) in a laboratory. The transmittance for the four types of red tinted contact lenses was determined in the visible spectrum between 400 to 700 nm (Figure 1).

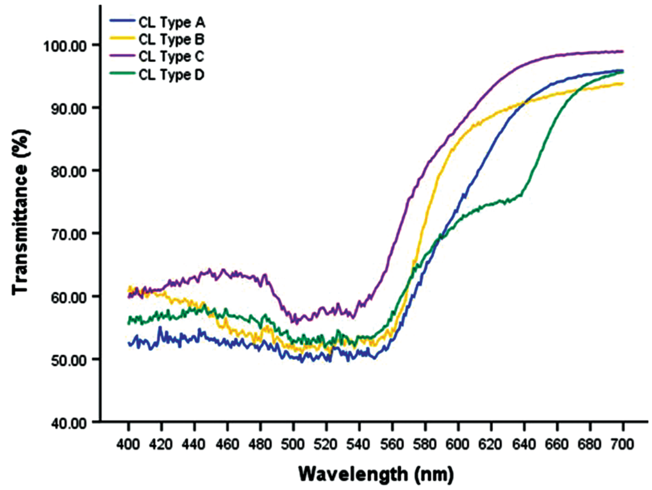

Figure 1 Spectral transmittance of each red tinted contact lens CL: Contact lens.

The four types of RCL transmit most light in the red region of the spectrum between 560 to 700 nm. The largest confusion wavelengths for red-green defects are where the M and L cones overlap, which is between 540 to 580 nm[9]. It can be seen from Figure 1 that red tinted contact lenses Types A, B and D have the lowest transmission in this region.

Procedures This was a randomized pilot study. Subjects were contacted *via* phone and invited to participate in this study. Those who were interested were given an appointment by a masked researcher. After a briefing on the protocols and procedures, the six subjects signed a written consent and were willing to participate in this study. They first underwent a comprehensive eye examination at the Optometry Clinic, Universiti Kebangsaan Malaysia. During the eye examination, eye dominancy was determined using the Miles Test.

Then, an Ishihara Test 38-plate Edition (Kanehara & Co., Ltd 1999, Japan) was conducted for screening congenital red-green colour deficiency. The test was conducted by viewing the plates with the non-dominant eye under the light of C.I.E Standard Illuminant C, providing 350 lx[19]. The plates were held 75 cm away from the adolescent and tilted so that each plate was at a right angle to the line of sight[20]. Each plate was viewed binocularly for a maximum of 4s. The subject was asked to read the number or trace the path on the plate. When the subject could not read the number or trace the path correctly, this was recorded as an error score. The total number of errors (or test error scores) made in identifying the plates was calculated by summing the number of errors made from 37 plates. If the subject made four or more errors in the test, the subject failed the test and was categorised as a red-green defective.

Table 1 Demographic data of subjects

Subjects	Age (y)	Gender	Non-dominant eye	Non-dominant eye distance visual acuity	Colour vision defect (FM 100 hue test)	TES
1	23	Male	Right eye	6/6	Protanomaly/protanopia	180
2	24	Male	Right eye	6/6	Deuteranomaly/deuteranopia	200
3	20	Male	Left eye	6/6	Protanomaly/protanopia	187
4	20	Male	Left eye	6/6	Protanomaly/protanopia	149
5	20	Male	Left eye	6/6	Protanomaly/protanopia	165
6	25	Male	Left eye	6/6	Diffuse colour discrimination	199

FM 100 Hue: Farnsworth-Munsell 100 Hue; TES: Total error scores.

FM 100 Hue test was then done with the non-dominant eye to classify the type of CVD. The test was conducted under C.I.E. Standard Illuminant C at 780 lx[21]. Illuminance for FM 100 Hue was measured using a lux meter each time before data collection. Standard administration procedures were followed. For each box, the intermediate caps were removed from the box and placed in random arrangement while the subject looked away. The subject was then asked to place the intermediate caps in the correct order in the box between the two fixed caps, with as little difference in hue between the neighbouring caps as possible. The same procedure was done for all four boxes. The order in which the subjects placed the caps was recorded.

Next, RCL were inserted into the non-dominant eye. The choice of contact lens to be inserted was done randomly using a "Research Randomizer" by a masked researcher. Each of these lenses was labelled as A, B, C, or D on its container by the principal investigator. The Ishihara test was conducted again after the insertion of all four types of RCL. There was a 15-minute adaptation period before colour vision tests were performed. Here again, the subject was asked to read the number or trace the path on the plate. When the subject could not read the number or trace the path correctly, this was recorded as an error score. The total error made (or test error scores) while wearing RCL were calculated by summing the number of errors made from 37 plates. The subjects were also asked to choose the most comfortable contact lenses subjectively. The results were then analysed before the identity of the lenses was revealed to the masked researcher by the principal investigator.

The mean total error score (TES) was calculated for all subjects. The subjects were then divided into two groups based on mean TES. TES less than mean TES were considered to be moderate, and TES more than mean TES was considered as severe.

Analysis Ishihara test error score was recorded manually on a recording sheet. Diagnosis of the type of colour vision defect using the FM 100 Hue Test was determined using a web-based scoring software (www.torok.info/colorvision/fm100.htm). TES were also obtained from this software. SPSS version 25 was used to analyse the data. Descriptive statistics was used to report demographic data and the Ishihara test error scores for baseline with no contact lens and each red-tinted contact lens. A repeated measures ANOVA was conducted to compare the effect of red-tinted contact lens types on Ishihara test error scores.

RESULTS

The demographic data of the six subjects in this study were shown in Table 1.

The mean age of subjects was 22.0±2.3y. Four subjects had protanomaly/protanopia, one subject had deuteranomaly/deuteranopia and one subject had diffuse colour discrimination. Since an anomaloscope was not used, it could not be ascertained if the subjects were anomalous trichromats or dichromats. Four out of six subjects (66.67%) were dominant in the right eye. All subjects were able to achieve habitual monocular distance visual acuity of 6/6 with the Snellen Chart before the colour vision tests were administered.

Figure 2 shows the Ishihara Test error scores with no contact lenses and with the four types of RCL [Types A (11.5±7.6), B (9.7±4.5), C (26.0±5.2), and D (19.7±6.7)]. Fewer errors were made when red-tinted contact lens Types A and B were used.

A repeated measures ANOVA with Greenhouse-Geisser corrections showed that there was a highly significant effect of red-tinted contact lens type on Ishihara error score [$F(2.056, 10.282)=30.214$, $P<0.001$]. Pairwise comparison with Bonferroni corrections revealed that error scores with lens Type B were significantly lower than errors made when no lens was worn, and with lens Type C and Type D (all $P<0.01$). Mean error scores with Lens B were also lower than those made with lens Type A, however, they are not significantly different (Figure 2).

The mean TES and standard deviation for all six subjects were 180±20. The subjects were then divided into two groups based on the mean TES. One group was those with TES less than 180 and the other group was those with TES above 180. Figure 3 shows the mean improvement in Ishihara error scores for subjects with TES of less than 180 and more than 180. RCL Type B showed the highest improvement in Ishihara error score, which is 0.50, 95%CI (0.09, 0.91) for colour

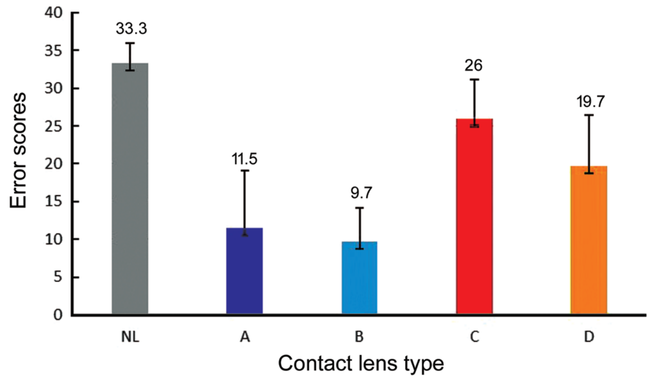

Figure 2 Ishihara error scores with contact lenses Types A, B, C, D and no contact lens A: Type A red tinted contact lens; B: Type B red tinted contact lens; C: Type C red tinted contact lens; D: Type D red tinted contact lens; error bars represent standard deviation of the mean. NL: No contact lens.

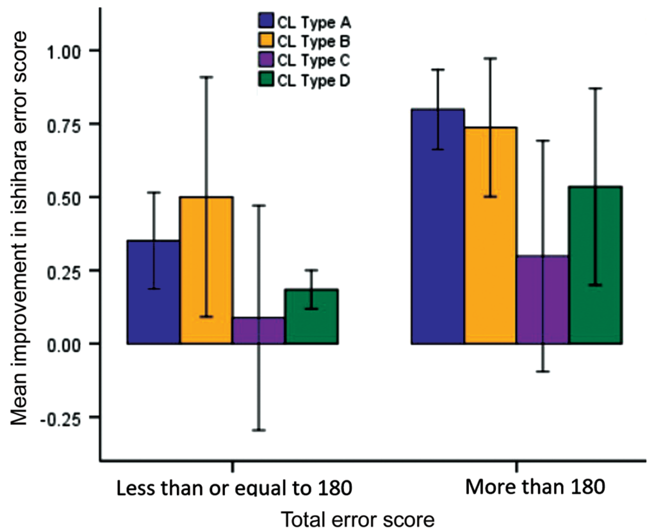

Figure 3 Mean improvement in Ishihara error score for total error score (TES) groups.

deficient subjects with TES values of 180 and below. Whereas for colour deficient subjects with TES above 180, RCL Type A showed the highest error score improvement, which is 0.80, 95%CI (0.66, 0.93). The error bars were plotted with 95%CI.

DISCUSSION

In this study, the results of the Ishihara test showed that colour deficient subjects made fewer errors (or error scores) when tested while wearing the red tinted contact lenses as compared to baseline, that is, without any contact lenses. This is consistent with previous reports which demonstrate that red tinted lenses can improve performance in the Ishihara test[13-14,22-23]. Our results show that red tinted lenses Type A and B induced significantly less Ishihara error scores compared to red tinted contact lens Types C and D. This is likely because these two red tinted contact lenses can block ranges of wavelength that cause similar levels of activity between the red and green cone receptors. Red-tinted contact lens is considered effective in colour deficient population when it can reduce the transmittance at a specific range of wavelengths, where the spectral sensitivities of L cones and medium wavelength sensitive M-cones overlap[14]. The spectral transmittance of the red tinted contact lens Types A and B have a lower light transmission at 450-568 nm and could reach 90% transmittance beyond 637 nm. Although red tinted contact lens Type D has similar transmittance as lens B at 450-568 nm, it could only reach 75% of light transmission at 637 nm. While for Type C, it could only absorb about 27%-45% at 450-568 nm although the transmittance at 637 nm was the highest, which was 96%. Therefore, contact lenses Types C and D did not perform well as an aid for the colour vision defective subjects in this study. Previous studies have also recommended blocking out wavelengths of ranges, 480 to 500 nm and 550 to 580 nm to enhance the colour vision of the colour blindness patients[9]. The red-coloured filter absorbs short and medium spectral wavelength ranging from blue to green and transmits long-wavelength light. For red-green CVD observers, certain bluish and greenish colours appear darker while certain reddish colours appear brighter when using these red-coloured filters. Therefore, a red-coloured filter modifies the luminance mechanism. The colour vision tests are based on chromatic contrast and equal luminance between the symbols and the background. The red filter, however, induces differences in the luminance between combination colours of reddish and greenish colours. This luminance cue results in the improvement in red-green CVD observers' performance on the colour vision tests and has been documented in several studies[3,13,24]. Transforming the chromatic contrast into luminance contrast could help colour defectives differentiate coloured objects. However, results from different studies are inconsistent. There are variable differences in the effect of a coloured filter on colour vision between the protan and deutan types. As such, it is not clear as to how red-green CVD observers utilize the luminance cues induced by coloured filters.

TES obtained from the FM 100 Hue test were used to determine the severity of CVD in this study. The subjects had TES ranging from 149 to 200. The TES values were used to divide the subjects into two groups, which were moderate and severe colour deficiency so that a suitable contact lens can be determined for each group. It was seen that red tinted contact lens Type A induced less Ishihara error scores for subjects with TES of more than 180 whereas Type B induced less Ishihara error scores for subjects with TES of less than 180. It is possible that subjects with greater error scores had a more severe red green deficiency and therefore needed a filter that could block out more wavelength between 550-580 nm. Type A lens compared to Type B blocked out more wavelengths between 550-580 nm.

There are many colour filter aids studies of spectacle lenses and contact lenses which consider these factors[8,14]. The colour filter aids, be it spectacle lenses or contact lenses, use the same concept of blocking certain wavelengths of the human's colour vision spectrum. For example, X-chrome lenses also work by absorbing wavelengths of 500-570 nm[3]. ChromaGen lenses were also found to be effective in reducing error scores in colour vision tests[15]. Based on a study by Salih *et al*[8], Atto's dye was also created to reduce overlapping wavelengths (545-575 nm) to help the colour deficient subjects distinguish red and green colours. According to Salih *et al*[25] study, the design of contact lenses for colour deficient populations should consider the transmittance at wavelengths other than the confusion wavelength. For example, gold nanoparticles are now being incorporated into colour vision aids as they can provide transmittance of 90% for wavelengths less than 500 nm and greater than 600 nm. Maximum transmissions are required at the unaffected wavelengths so that other color perceptions are not being disturbed. In the present study, contact lenses Type A and B which were more effective reached 90% of light transmissions at 637 nm.

There are several limitations in the present study. This study was conducted during the Corona Virus Disease-19 pandemic and many obstacles were encountered during the data collection process. Therefore, the sample size for the study was small and could have resulted in type 2 errors resulting in false negatives. Increasing the sample size will increase the power. An underpowered study could result in a reduced chance of detecting a true effect. Many statistical analyses cannot be applied and only a few non-parametric tests can be used. Due to the small and incomplete colour deficient population in this study, the data was analysed without dividing into a more detailed colour deficient category. In addition, anomaloscope testing should be done to precisely diagnose the type and severity of colour deficiency. The comfort and preference of wearing the RCL should have been measured using a questionnaire to give a better understanding of the performance of the contact lenses. Another limitation is that only the Ishihara clinical test was done to observe effectiveness of the lenses. In the future, the performance and subjective responses of colour defectives while conducting their daily activities with these RCL should be investigated.

In conclusion, this study showed that RCL can improve Ishihara error scores. RCL with lower transmission at 450-568 nm and 90% transmittance beyond 637 nm were the most effective. Lenses which could block more light between 550-580 nm were more effective for colour defectives with more severe colour defects. Colour defectives with moderate and severe colour vision defects can benefit from using red tinted lenses as the red tint changes the luminance contrast making it easier for the colour defectives to make fewer errors on the Ishihara test. Further studies are needed to ascertain if the red tinted lenses can benefit colour defectives in real life environment.

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