CLINICAL AND EXPERIMENTAL
OPTOMETRY

Orienteers with poor colour vision require more than cunning running

Clin Exp Optom 2008; 91: 6: 515–523 DOI:10.1111/j.1444-0938.2008.00294.x

Jennifer A Long BOptom (Hons) MSafetySc
Barbara M Junghans BOptom GradDipHEd PhD FAAO
School of Optometry and Vision Science, University of New South Wales, Sydney, Australia
E-mail: b.junghans@unsw.edu.au

Submitted: 3 May 2007
Revised: 11 February 2008
Accepted for publication: 4 March 2008

Background: Highly detailed colour coded maps are used in the sport of orienteering to enable competitors to navigate from one check point to another and to provide guidance on the nature of the terrain to be traversed. The colours are defined by the International Orienteering Foundation (IOF) and are said to have been chosen so they will not be confused by competitors who have abnormal colour vision. However, there are anecdotal reports that individuals with colour vision defects do have problems with the colour coding.

Method: A Minolta Spectrophotometer CM-503i was used to measure the CIE x,y chromaticity co-ordinates and the reflectances of the standard colours recommended by the IOF for the colour coding of orienteering maps, as well as the colours on two maps used in orienteering events.

Results: Four pairs of IOF standard colours are likely to be confused by protan observers and four pairs by deutan observers. There were three pairs of colours likely to be confused by both deutan and protan observers on one of the competition maps and one pair likely to be confused by protan observers on the other map. Some of the colours on the actual competition maps differed noticeably from the standard IOF colours.

Discussion: Orienteers with more severe forms of abnormal colour vision are likely to be disadvantaged by their inability to differentiate some colours used on orienteering maps. The IOF should choose different colours that are less likely to be confused or should employ a redundant code (such as a pattern or texture). There is need for better quality control of the colours of competition maps to ensure they do conform to the IOF standard colours.

Key words: colour space, defective colour vision, map-making, maps, orienteering

Orienteering is an individual sport in which a compass and a specially prepared map are used to choose the best route through a series of marked checkpoints in the bush (Figure 1). Although not as popular in Australia as in Northern European countries, approximately 5,500 Australians participate in orienteering, of whom a little more than half are male and almost half are over the age of 40 years. Even though the competition leaders always race against the clock, the majority of orienteers compete at a pace to suit themselves. Those with poorer physical ability simply take longer but for many this means they have a better chance to enjoy the scenery.

An orienteering map is extremely detailed and colour coded to convey not only geographic and other physical features such as the contours of the land

Figure 1. An orienteering control set in the bush. The identification on the control confirms for competitors that they are at the correct location. Proof that the orienteer has visited the site is achieved either by the orienteer touching a microchip carried on a hand onto an electronic box installed on the stand or by the orienteer punching a card with the 'stapler-like' clipper on the control strand that leaves a unique pattern of holes in the card.

(brown), rock faces (black), watercourses (blue), termite mounds (brown), fences, buildings (black) et cetera, but also the runnability of the land (Figure 2). Orienteering maps employ 'sequential' colour schemes,[1] whereby 'darker shades represent more'. For example, shades of yellow are used to denote areas of good visibility but varying runnability: heathland with good visibility but slow runnability is assigned a paler yellow, while grazing land with good visibility and faster runnability is represented in a rich yellow. On the other hand, shades of green are used to indicate forest density, which in turn, affects runnability: areas of less dense forest are represented in pale green while dark green is used for bush considered too thick to penetrate, such as blackberries. In addition, vertical blue or black lines are superimposed at five-centimetre intervals to indicate magnetic north-south. The course, represented by a series of six-millimetre circles connected by lines, is overprinted in purple. Therefore, it is critical to the enjoyment of orienteering that the orienteer has good colour discrimination for the various shades of red, green, yellow, brown, blue and grey.

Prior to 1973, most Australian orienteering maps were printed in black and white.[2] The inclusion of colour, with the ability to include more information, was seen as a significant advance and a step toward providing maps of a standard similar to those used overseas. Orienteering Australia has adopted a pantone matching system (PMS) colour spot printing scheme (which is a standardised ink colour system widely used in the graphic arts industry that includes approximately 800 basic colours for both coated and uncoated paper) in accordance with the International Specifications for Orienteering Maps (ISOM 2000)[3] created by the International Orienteering Federation (IOF) for use by orienteering map-makers (Figure 3). The IOF colours were chosen in 1990 for use by orienteers with colour vision deficiencies (personal communication with the Chairman of the IOF Map Commission). The six-colour scheme includes three saturations of green, four of yellow, two of blue and three of brown, black and a grey. Two of the yellow samples (50 and 36 per cent) have a mildly textured pattern, while the two samples with higher saturation are solid. In the Australian specification, only the grey differs from the IOF scheme, being a little darker.

It is well documented that those with colour defective vision have greater difficulty reading and interpreting coloured maps than those with normal colour vision. Birch[4] suggests that colour defective individuals can take up to twice as long to extract information from geographical maps, while Olsen and Brewer[5] report that colour defective individuals have slower reaction times for making decisions and an increased likelihood of error when reading maps. Interestingly, when Olsen and Brewer[5] provided modified maps with colours that were not likely to be confused by a colour defective person, reaction times were still slower for those having a colour vision deficiency. When interviewed, one individual admitted that he had learned not to trust colour-coded maps and so spent more time reading the map. Slower response times and higher error rates have also been reported for colour defective persons viewing video displays,[6] coloured signal lights[7] and when searching for target objects that are colour coded.[8] In a background questionnaire administered to their subjects, Olsen and Brewer[5] found that compared to colour normal persons, those with red-green impairments 'were less experienced with maps and held more negative attitudes toward them'.

Adding to the difficulty of reading coloured maps is the fact that orienteering is an outdoor sport where maps are read under a variety of weather and lighting conditions. There are time-pressures to read the map quickly and the map is often read while running. Frequently the size of the coloured areas on the map is of the order of only two millimetres (for example, a 20-metre feature on a map with scale 1:15,000 would be represented as a patch only 1.67 mm wide). Also, contour lines and route indicators are less than 0.2 and 0.5 mm across, respectively (Figures 2 and 4). For small areas of colour, the probability of a colour naming error is greater for colour defective individuals when viewing a line stimulus compared to viewing a dot stimulus.[9] Furthermore, in attempting to keep maps within A4 dimensions, a legend is not always included for reference, as all orienteers are issued with a copy of the internationally-accepted legend when they join the sport. For these reasons, the colours of orienteering maps are intrinsically difficult to interpret, especially for those with more severe colour vision deficiencies.

Approximately eight per cent of males and 0.4 per cent of females are born with a red-green colour vision deficiency.[4] If this representation were maintained in orienteers, an estimated 220 male and

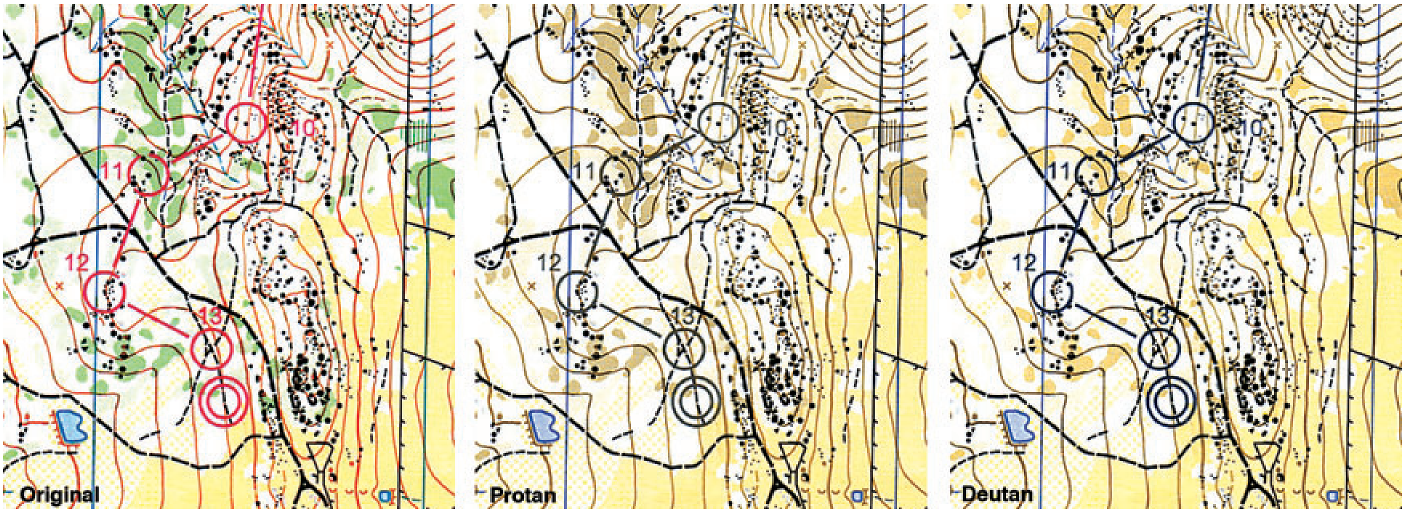

Figure 2. A portion of the map 'Yewrangara' used for the New South Wales Orienteering Championships in 2005, which is representative of bush orienteering maps in Australia plus simulations of views by colour defective orienteers rendered using Vischeck plug-ins for Adobe Photoshop (www.vischeck.com). Left: The original colour scheme. Middle: Portrayed as viewed by an orienteer with a protan defect. Right: Portrayed as viewed by an orienteer with a deutan defect.

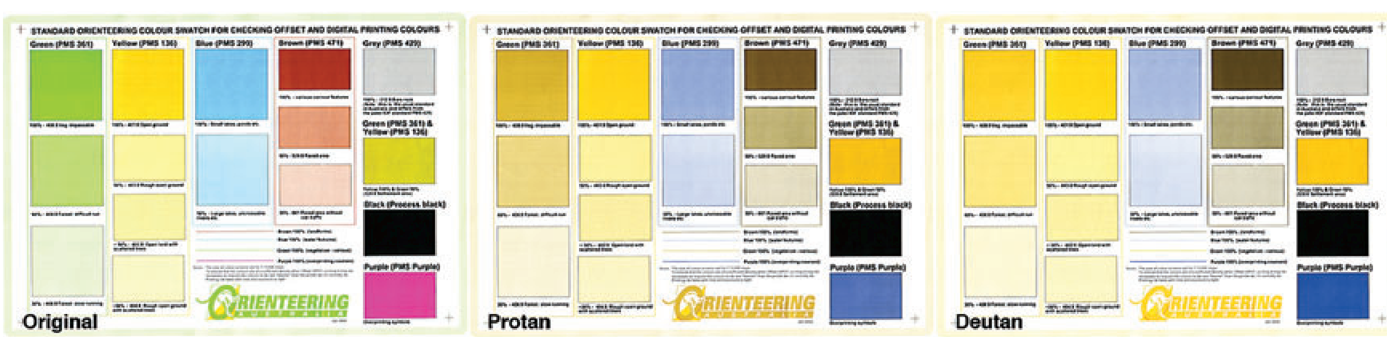

Figure 3. The PMS colour swatch issued by Orienteering Australia for checking offset and digital printing of orienteering maps plus simulations of views by colour defective orienteers rendered using Vischeck plug-ins for Adobe Photoshop (www.vischeck.com). Left: The original colour scheme. Middle: Portrayed as viewed by an orienteer with a protan defect. Right: Portrayed as viewed by an orienteer with a deutan defect.

11 female orienteers in Australia would have a colour vision deficiency. Although largely anecdotal, there is evidence that some orienteers have colour vision deficiencies and wish to continue orienteering. Maps should be easily readable by these individuals so that they are not disadvantaged in orienteering competitions.

Is there evidence that orienteering map-makers have not risen to the challenge of providing fair competition? Anecdotally, the answer is yes. Typically, orienteers congregate around the result board after an event, map in hand, discussing route choices and difficulties on the course. During one such discussion, an orienteer expressed exasperation with a particular route choice. His friends were amazed that he should even consider this option, as the stretch of ground was clearly represented on the map as 'slow run', designated by a medium density green. The question of why he had not deviated 100 metres to access a clear run across open fields as indicated on the map in yellow, elicited the response that he 'could not see the difference'. In addition, several event organisers in Australia have reported (by personal communication) that some orienteers have complained that maps are

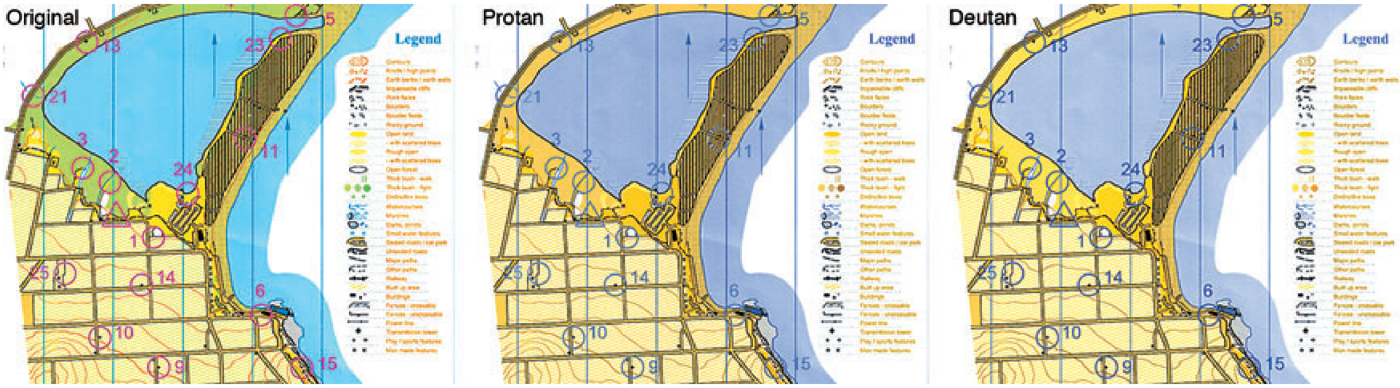

Figure 4. A portion of the Dee Why map used for one of the Summer series of mid-week late afternoon 'score orienteering' suburban events plus simulations of views by colour defective orienteers rendered using Vischeck plug-ins for Adobe Photoshop (www.vischeck.com). Left: The original colour scheme. Middle: Portrayed as viewed by an orienteer with a protan defect. Right: Portrayed as viewed by an orienteer with a deutan defect.

not being designed with colour deficient competitors in mind.

The objective of this study is to evaluate typical maps and map-related documents used in orienteering in Australia to determine whether the internationally specified colours and/or the colours on the maps used are likely to be confused by a person with a red-green colour vision deficiency.

METHODS

Three coloured documents used for orienteering in Australia were obtained:

- The standard PMS colour swatch published by Orienteering Australia (January 2004) for colour spot checking offset and digitally printed colours (Figure 3)
- The 'Yewrangara' orienteering map used for the 2005 NSW Championships (Figure 2)
- The 'Dee Why Lagoon', Sydney, orienteering map used for local minor events (Figure 4).

The colours in each of these three documents were measured with a Minolta Spectrophotometer CM-503i, reference light source D65. As the minimum area required for spectrophotometric measurements is a circle of four-millimetre diameter, pieces of map were cut and where necessary pasted together to achieve an area large enough for measurement. The x-y colour specifications and the reflectance, Y, for each colour were obtained.

For each document, the x-y colour co-ordinates were plotted on replicas of the Commission Internationale de L'Éclairage (CIE) 1931 diagram. Colour confusion lines emanating from the copunctal points for protan and deutan deficiencies were added to the diagram. Two colours were deemed to lie on a confusion line if a line joining the two colours also passed through the copunctal point. This enabled identification of any colours used for orienteering maps, which could possibly be confused by individuals with the more common colour vision deficiencies.

Each document was scanned using a Canon CanoScan Lido 20 scanner and the image transformed using Vischeck software (www.vischeck.com) to give an indication of how each document might appear to an individual with either a protan or deutan colour vision deficiency.

RESULTS

The (CIE) x-y colour specifications and luminous reflectances for each colour on the documents are given in Table 1, along with the associated meaning of each colour, when used in orienteering maps. The x-y co-ordinates were plotted on CIE 1931 chromaticity diagrams to determine if any colour combination were likely to be confused (Figures 5, 6 and 7).

Table 2 shows the colour combinations that are likely to be confused by individuals with protan and deutan colour vision deficiencies. It must be noted that depending on the severity of the colour vision deficiency, these colours might not be confused by all colour defective individuals all of the time. These colour confusions ignore luminous reflectance (or brightness), which might be used by colour defective individuals to assist in colour discrimination. On the PMS colour swatch, four colour pairings lie on a confusion line for both protan and deutan colour deficiencies. Three colours used in the Dee Why Lagoon map lie on a confusion line for protan and three colours lie on a confusion line for deutan colour vision deficiencies. Although visually more complex due to the presence of many brown contour lines and black boulders, the Yewrangara map uses less colour coding than the Dee Why Lagoon map. There is only one colour combination that

Document	Colour	Colour co-ordinate (x)	Colour co-ordinate (y)	Luminous reflectance (%) (Y)	Associated meaning of colour in orienteering
PMS swatch	Green 100%	0.3135	0.4667	39.99	Impassable vegetation
	Green 60%	0.3144	0.4061	51.39	Forest very slow run
	Green 30%	0.3131	0.3628	63.98	Forest, slow run
	Brown 100%	0.4658	0.3844	20.71	Landforms, earth features
	Brown 50%	0.3796	0.3557	38.04	Paved, sealed road
	Brown 30%	0.3433	0.3410	54.86	Paved area
	Yellow100%	0.4488	0.4331	56.10	Open ground, fast run
	Yellow 50%	0.3808	0.3867	66.56	Rough, open land, scattered trees, fast run
	Yellow 30%	0.3529	0.3618	72.02	Rough open ground, slow run
	Green/yellow	0.4109	0.4529	43.79	Private property
	Blue 100%	0.2223	0.2630	37.47	Water features
	Purple	0.3443	0.2134	19.95	Control points
	Black	0.3264	0.3370	7.84	Man-made features
	Grey	0.3081	0.3284	45.43	Bare rock
Yewrangara	Dark green	0.2962	0.3822	45.35	
	Pale green	0.3018	0.3454	63.52	
	Pale yellow	0.3571	0.3692	62.93	
	White	0.3034	0.3173	81.03	
	Blue	0.2513	0.2732	46.30	
	Purple	0.3983	0.2603	21.80	
Dee Why Lagoon	Dark green	0.2642	0.5178	25.89	
	Medium green	0.3195	0.4392	50.34	
	Dark yellow	0.4427	0.4556	52.39	
	Pale yellow	0.3862	0.4135	63.14	
	Blue	0.2373	0.2829	41.45	
	Brown (road)	0.4096	0.3914	47.22	
	Grey	0.3073	0.3197	50.30	
	Purple	0.3422	0.2374	30.46	
	White	0.3032	0.3160	80.67	

Table 1. CIE x-y colour co-ordinates, brightness values and potential colour confusions for the Orienteering Australia PMS colour swatch, Yewrangara and Dee Why Lagoon maps

lies along the protan confusion line for the Yewrangara map.

The scanned image of each document and the associated Vischeck transformations that simulate appearances for persons with protanopia and deuteranopia are shown in Figures 2, 3 and 4.

A comparison was made of the colours used on the orienteering maps against the colours specified on the PMS colour swatch (Table 3). When plotted on a CIE 1931 diagram (Figure 8), it can be seen that the colours were not faithfully reproduced on the maps, although for some colours the difference appears marginal.

DISCUSSION

Some of the colours used on the PMS colour swatch for competitive orienteering maps, as specified by the International Orienteering Federation, lie along red-green colour confusion lines and may be insufficiently different for a red-green colour defective orienteer to accurately distinguish. This will be more so for those with more severe colour vision deficiencies, such as dichromacy. Therefore, orienteering administrators appear to have given an unfair competitive advantage to

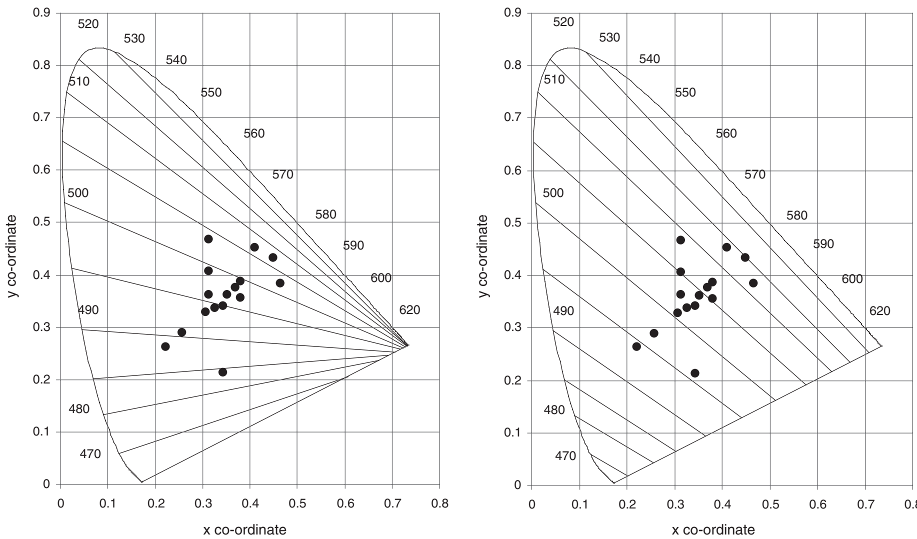

Figure 5. X-Y co-ordinates for all nominated PMS colours on the Orienteering Australia colour swatch for checking offset and digital prints of maps plotted on the 1931 CIE diagram. Left: CIE diagram superimposed with protan colour confusion lines. Right: CIE diagram superimposed with deutan colour confusion lines.

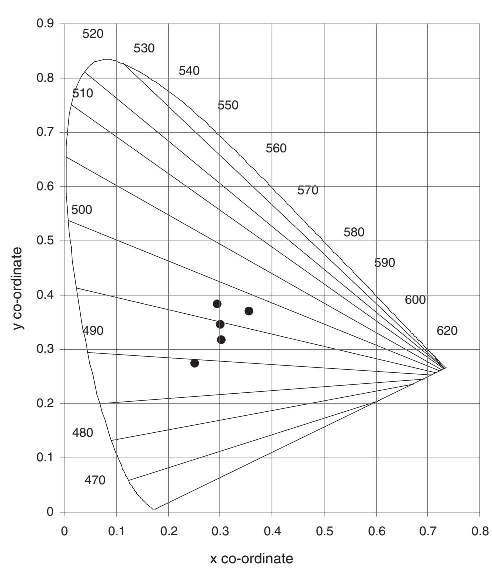

Figure 6. X-Y co-ordinates for each colour used on the Yewrangara map on a CIE 1931 diagram superimposed with protan colour confusion lines.

colour normals. In addition, despite attempts to standardise, the colours used are not always reproducible on the finished map.

Only congenital red-green deficiencies have been taken into account in the current analysis. Tritan colour vision deficiencies could lead to confusions of green with blue and white with yellow but the incidence of congenital tritan deficiencies is less than 1 in 10,000 people.[4] Acquired tritan deficiencies can occur secondary to ocular conditions, such as cataracts, glaucoma and macular degeneration or due to occupational exposure to chemicals[10] but are more likely to be accompanied by visual loss that may make map-reading more difficult and discourage participation in orienteering.

There are several options to accommodate orienteers with defective colour vision. An obvious strategy is to avoid colours that lie along colour confusion lines. As it would be difficult to avoid conflicting colours for protans, deutans and tritans simultaneously, red-green colour defective orienteers should be targeted. If the orienteer is made aware that a map caters for red-green colour vision defects through the use of unambiguous colours,[1] then from a psychological point of view greater trust might ensue and hence, greater fluency in map reading. The use of fewer and more saturated colours would also minimise confusion by some colour defective orienteers. Smith[11] suggests that only five to eight different colours can be reliably discerned under good conditions by normal observers. In addition, density differences should be greater than 15 per cent (for example, 30 per cent grey and 45 per cent grey) to minimise map-reading errors due to limitations in the discrimination of the eye.[12,15] For red-green colour defective orienteers, blue, yellow, white, grey and black are readily discerned. Yellow should be limited to two or three different tints, as differentiation between yellow tints is more difficult than for other colours[12] and it is sometimes difficult to print dark saturated yellows.[13] Maps could even be made relatively achromatic and equally readable in black and white (that is, the coloured version once photocopied

Document	Colours that lie along a confusion line*	Colour vision deficiency likely to make confusion
PMS swatch	Green 100% / brown 100%	Protan
	Green 60% / yellow 50%	Protan
	Yellow 100% / green-yellow	Protan, deutan
	Green 30% / brown 50% / brown 30%	Protan
	Blue 100% / purple	Deutan
	Green 60% / brown 50%	Deutan
	Green 30% / brown 30%	Deutan
Yewrangara map	Dark green / pale yellow	Protan
Dee Why map	Medium green / pale yellow / brown road	Protan
	Dark green / pale yellow / brown road	Deutan

*The purported colour confusions ignore possible effects from luminous reflectance

Table 2. Colours that lie along a confusion line

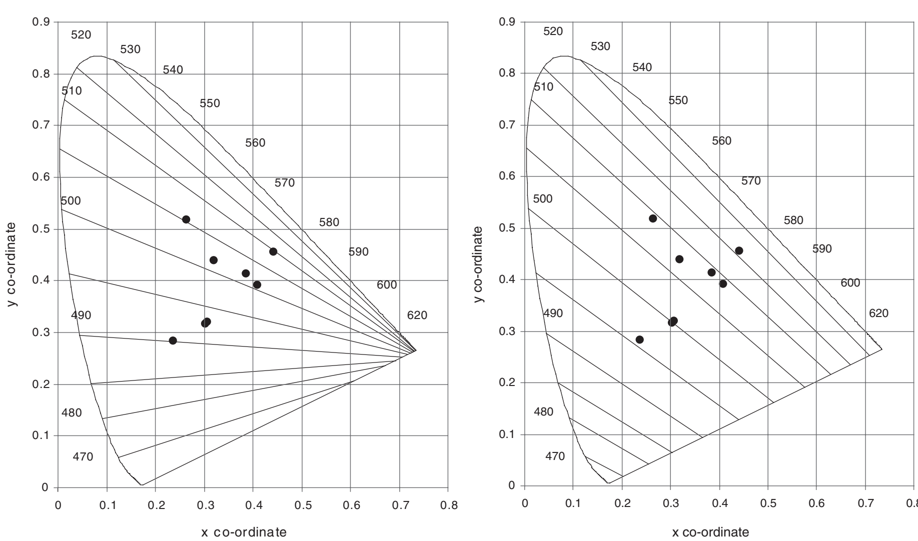

Figure 7. X-Y co-ordinates for each colour used on the Dee Why Lagoon map. Left: CIE 1931 diagram superimposed with protan colour confusion lines. Right: CIE 1931 diagram superimposed with deutan colour confusion lines.

on a black and white copier remains legible for what it represents). Grey-tone maps would minimise the disadvantage of colour defective vision but may be seen as a backward step, as the use of colour has been shown to reduce errors and search time for displays[6] and maps, particularly if the colour is accompanied by a label.[14]

A greater use of texture to augment the use of colour (for example, geometric hatching) might be investigated. However, the use of texture is limited because some areas on orienteering maps are only millimetres in size, which will preclude pattern recognition. Supplementary coding such as encircling important areas may also assist speedier differentiation but this would not be suitable for orienteering maps due to the great amount of detail already on the map (Figure 2). For events where there is no legend on the map, a simple step would be to print a separate legend at the time of map printing to be available to those who wish for reference on the course.

Differences in reflectance were found between the colours printed on the maps. It could be argued that colour defective orienteers are able to use these brightness cues, especially for colours that lie along a confusion line. Yet, relying solely on brightness cues would be a time disadvantage for the colour defective competitor as it has been shown that colour enhances ability to search and read maps[14] and the orienteer would be dependent on carrying a map legend for reference during an event. A related factor is the ambient illumination, which can vary during an event from full sunshine to poor light under a dense canopy of forest.

Even if Orienteering Australia, or more importantly the IOF, were to develop a new PMS colour scheme, there is the risk that the colours printed on maps may not be faithfully reproduced and still pose a problem. The differences in colour might arise from the type of printer, the age of the toner or the kind of paper.[16] For important orienteering events, organisers use offset or laser printing on waterproof paper to allow for possible tearing of the regulatory plastic map case and subsequent spoilage from rain, sweat or accidental contact with water in creeks. To save costs for minor events, a home inkjet printer and a lesser grade of paper might be used and the competitor left to encase the map in plastic. It appears that a number of Australian event organisers of local events use their home printer and simply spot check against the PMS swatch in their homes. Failure to ensure daylight illumination plus a personal bias in colour perception may lead to a false appreciation of the adequacy of a print batch and be a further factor in the lack of standardisation.

In Australia, orienteering maps are generally produced using OCAD computer-aided design software (www.ocad.com), which is now regarded as the international standard for orienteering map design and encompasses the IOF colour specifications

Colour	PMS			Yewrangara			Dee Why		
	x	y	Y	x	y	Y	x	y	Y
Dark green (100%)	0.3135	0.4667	39.99	0.2962	0.3832	45.35	0.2642	0.5178	25.89
Medium green (60%)	0.3144	0.4061	51.39	n/a	n/a	n/a	0.3195	0.4392	50.34
Pale green (30%)	0.3131	0.3628	63.98	0.3018	0.3454	63.52	n/a	n/a	n/a
Dark yellow (100%)	0.4488	0.4331	56.10	n/a	n/a	n/a	0.4427	0.4556	52.39
Pale yellow (30%)	0.3529	0.3618	72.02	0.3571	0.3692	62.93	0.3862	0.4135	63.14
Blue (50%)	0.2578	0.2896	37.47	0.2513	0.2732	46.30	0.2373	0.2829	41.45
Purple	0.3443	0.2134	19.95	0.3983	0.2603	21.80	0.3422	0.2374	30.46
Grey	0.3081	0.3284	45.43	n/a	n/a	n/a	0.3073	0.3197	50.30

Table 3. A comparison of CIE x-y colour co-ordinates and luminance reflectance (Y, %) for colours on the PMS colour swatch versus those colours actually used on the Yewrangara and Dee Why orienteering maps

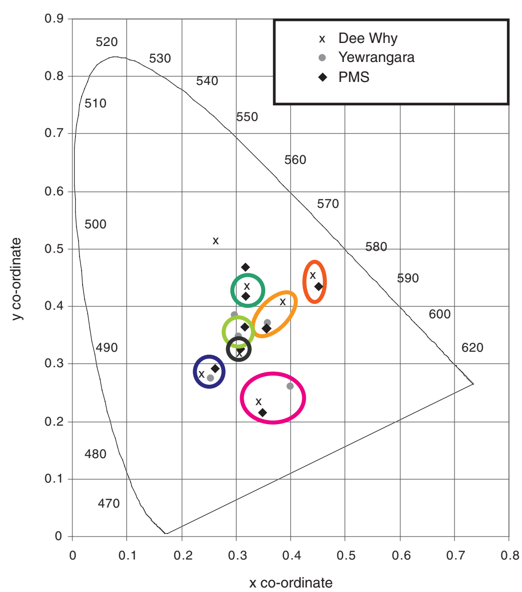

Figure 8. Clusters of X-Y co-ordinate variants for each of the colours as printed on the Orienteering Australia PMS colour swatch and the Dee Why Lagoon and Yewrangara orienteering maps

within the software. The maps used for this study were both designed using a recent version of OCAD, yet some differences between the colours on the swatch and the purportedly same colours on the maps were found (Figure 8). Halsey and Chapanis[17] have shown that large differences in tolerance to just noticeable differences in colour may exist between observers.

To appreciate the dilemma of the red-green colour defective orienteer, map-makers could submit their planned colours to computer programs such as Vischeck and visually confirm that the colours on any given map can be distinguished by those with limited colour perception. It should be noted that such programs simulate only what it is believed colour defective individuals see and there may be errors introduced through scanning the map and when processing the information through the Vischeck filter. Such limitations pertain to the simulations presented in this paper.

Colour defective orienteers might also assist their own map-reading performance by using long wavelength pass lenses, which alter the relative brightness of colours and enhance differences between colours that otherwise appear identical. These lenses have been marketed under names such as X-Chrom, Chromagen, Colormax, Coloryte and Colorview. However, long wavelength pass lenses have the potential to distort other colours, to superimpose a blue-yellow deficiency over the existing red-green deficiency[18] and to reduce visibility in dim light.[19] Therefore, their use in orienteering might be limited to situations in which there is doubt about the meaning of colour on the map (for example, the orienteer might take the lens orienteering but use it only when reading a 'difficult' portion of the map). Notwithstanding the above comments regarding reflectance and brightness differences and the variable impact on colour defectives, comments from one orienteer issued with such a lens at the UNSW Colour Vision Clinic for use as a lorgnette indicated that the lens was immensely helpful.

CONCLUSION

Colour coding is used on orienteering maps to convey impediments to a competitor's speed through the terrain. As orienteering is a competitive sport, colour defective orienteers may be significantly disadvantaged, if the colours are not as readily discerned by them. This paper has shown that the current international colour system is not easy to use for orienteers with red-green colour vision defects. Therefore, it is recommended that the current PMS colour specifications for orienteering cartography be reviewed at the level of the International Orienteering Federation and that further specifications be developed regarding colour tolerances, paper reflectance and conditions of illumination during quality control checks. While some of the suggestions discussed in this paper may assist colour defective orienteers, the solution should not entail extra work or effort because of the time penalty imposed. By having a better understanding of colour space and factors affecting the fidelity of the entire process of cartography through to the printed map viewed in the forest, it should be possible to design a set of PMS colour specifications that ensure colour defective individuals have more equitable access into the sport of orienteering.

ACKNOWLEDGEMENT

We thank Professor Stephen Dain of the Optics and Radiometry Laboratory, UNSW, for use of the spectrophotometer and for supplying the base CIE diagrams.

REFERENCES

1. Brewer C. Evaluation of a model for predicting simultaneous contrast on color maps. *Prof Geogr* 1997; 49: 280–294.
2. Hogg DM. The preparation of orienteering maps. *Cartogr* 1974; 8: 187–190.
3. International Orienteering Federation. International specification for orienteering maps. 2000. Available from: http://www.orienteering.org/i3/index.php?/iof2006/document_library/rules_and_guidelines/mapping_standards.
4. Birch J. Diagnosis of Defective Colour Vision. London: Butterworth Heinemann, 1993.
5. Olsen J, Brewer C. An evaluation of color selections to accommodate map users with color vision impairments. *Ann Assoc Am Cartogr* 1997; 87: 103–134.
6. Cole B, Macdonald W. Defective colour vision can impede information acquisition from redundantly colour-coded video displays. *Ophthalmic Physiol Opt* 1988; 8: 198–210.
7. Atchison D, Pederson C, Dain S, Wood J. Traffic signal color recognition is a problem for both protan and deutan color-vision deficients. *Hum Factors* 2003; 45: 495–503.
8. Cole B, Maddocks J, Sharpe K. Visual search and the conspicuity of coloured targets for colour vision normal and colour vision deficient observers. *Clin Exp Optom* 2004; 87: 294–304.
9. Cole BL, Lian KY, Sharpe K, Lakkis C. Categorical color naming of surface color codes by people with abnormal color vision. *Optom Vis Sci* 2006; 83: 879–886.
10. Sharanjeet-Kaur, Mursyid A, Kamaruddin A, Ariffin A. Effect of petroleum derivatives and solvents on colour perception. *Clin Exp Optom* 2004; 87: 339–343.
11. Smith S. Color coding and visual search. *J Exp Psych* 1962; 64: 434–440.
12. Kimerling A. Color specification in cartography. *Am Cartogr* 1980; 7: 139–153.
13. Brewer C. Guidelines for selecting colors for diverging schemes on maps. *Cartogr J* 1996; 33: 79–86.
14. Shonz W, Trumm G, Williams L. Color coding for information location. *Hum Factors* 1971; 13: 237–246.
15. Pickle L, Herrmann D. The process of reading statistical maps: the effect of color. Available at: http://lib.stat.cmu.edu/scgn/v51/section1_3_0_1.html.
16. Harrower M, Brewer C. ColorBrewer.org: An online tool for selecting colour schemes for maps. *Cartogr J* 2003; 40: 27–37.
17. Halsey R, Chapanis A. Chromaticity confusion contours in a complex viewing situation. *J Opt Soc Am* 1954; 44: 442–454.
18. Hovis JK. Long wavelength pass filters designed for the management of color vision deficiencies. *Optom Vis Sci* 1997; 74: 222–230.
19. Swarbrick HA, Nguyen P, Nguyen T, Pham P. The ChromaGen contact lens system: colour vision test results and subjective responses. *Ophthalmic Physiol Opt* 2001; 21: 182–196.

Corresponding author:
Barbara M Junghans
School of Optometry and Vision Science
University of New South Wales
Sydney NSW 2052
AUSTRALIA
E-mail: b.junghans@unsw.edu.au