TRACK MARKERS:

Improving their visibility

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INTRODUCTION

A previous report (Laird, *C.A.S. Notes No. 92*, 1994) outlined some of the variables affecting track marker visibility in the bush/forest environment. This study set out to isolate a more visible orange hue and to determine the influence of a small variation in the triangular shape of the marker. The performance of people with colour vision defects (C.V.D.s) was of particular interest.

METHOD

Marker Colour

The colour of the current D.O.C. marker is orange, with a dominant wavelength of 597 nm, positioning it chromatically closer to red (600 nm) than yellow (580 nm). This was determined using an ACS Data Colour CSIII Spectrophotometer with standard daylight conditions (Appendix I). A 'white' and two further orange colours with dominant wavelengths 585 nm and 590 nm were formulated (Appendices I and II). The surface reflectance of all the orange colours and 'white' was between 0.40 and 0.46, and their chromatic purity was of the order of 83-84.6 %.

Marker Shape

Two triangular shapes (Figure 1) were used in the study. Their surface areas were each approximately 4,000 mm^2 The "D.O.C." shape represents the dimensions of the current D.O.C. marker, while the "EXP." shape presents a squatter and more compact visual target.

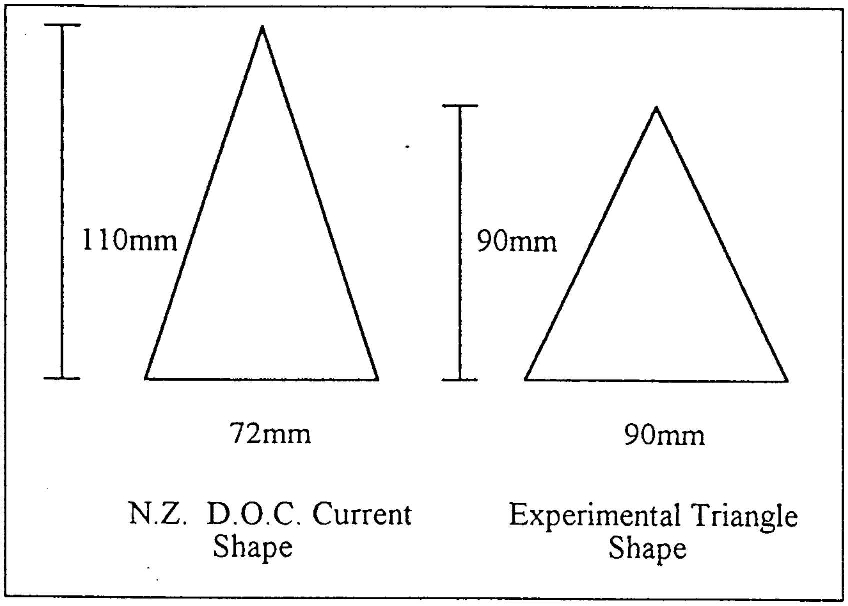


Figure 1 - *Triangle shapes used in this project.*

Investigation One - Auckland Domain

Eight different track markers included every combination of the four colours and two shapes. For each trial, a random selection of four markers were mounted outdoors on tree trunks at the edge of a forested area. Six trees were numbered 1-6, and the four markers being trialled were placed at a height of 1.6 metres on any four of these for each trial.

Subjects walked across a grassed area towards the trees and measurements were made of the distances from which each marker was first visible, using 5 metre intervals marked on the ground. This was repeated for three different approach angles; directly in front, and from 10 degrees on either side of centre.

The marker visibility distances from the trees were markedly less for the C.V.D. subjects and, for accuracy, these were measured using a metre wheel.

Investigation Two - Vinings Scenic Reserve, Hunua Ranges

This D.O.C. track runs up a spur and was selected because it has variable canopy and foliage, and also because it is not being frequently used. This meant that the exact route was not clear at many points along the track.

A distance of 950 metres up the track was marked out using 40 markers, ten markers in each of four colours. Markers were set in both directions of the track, with each subject timing their sightings both up and down the track. A random order was established using Eton Mathematical Tables. Markers were placed such that only one marker was visible at any one time, resulting in an average separation of 43 metres.

The instructions were to proceed up the track recording the time, via a stopwatch, at which each marker was first seen, and the time when each marker was reached. Markers had an identification code on a white card positioned at the base of the tree. This identification was recorded alongside the elapsed times to check which markers, if any, were missed.

SUBJECTS

All subjects had normal visual acuity. Investigation One used 18 invited volunteers, of whom 9 had a C.V.D. Subjects for Investigation Two were all members of the University of Auckland Tramping Club, and 5 of these had a C.V.D. The type of colour vision deficit was determined for each C.V.D. subject and is noted in Tables 1 and 2, on pages 4 and 6 respectively of this report.

RESULTS

Both of these studies were conducted in midwinter.

Investigation One - Domain Study

Under these 'ideal conditions' (uniform tree trunk colour, illumination and size, as well as a homogeneous background and no obstructions) white was more visible than any of the orange hues for both normal and C.V.D. subjects with apparently no significant influence from variation of the triangular shape (Table 1, Figure 2).

Table 1 : *Marker Visibility (mean distance in metres)*

SUBJECTS	MARKER							
	O 597nm DOC	O 597nm Exp	O 590nm DOC	O 590nm Exp	O 585nm DOC	O 585nm Exp	White DOC	White Exp
1	146.7	153.3	154.3	170	166.7	169	170	170
2	78.3	112	136	170	145.7	136	162.3	170
3	95.3	106.3	118.3	170	144.3	131.7	162.3	170
4	80.5	100	116.7	156.7	121.8	82.7	149	160.7
5	144.3	123.3	123.3	170	137.7	135	149.7	170
6	68.8	121.7	126.3	156.3	105.7	94.7	170	170
7	71	77.7	87.3	147.7	111.3	138.7	170	170
8	91.3	170	139	170	158.3	170	170	170
9	132.7	133.3	126.7	158.3	152.7	160.7	170	170
Mean	100.9	121.9	125.3	163.2	138.2	135.4	163.7	169
SD	31.6	27.8	18.4	8.6	21.1	30.5	8.8	3.1
10 deutan	15	70	36.7	110	64.7	106.7	116.7	121
11 deutan	67	129.3	80	121.7	106.3	106.7	115	138.3
12 protan	38.7	166.7	30.7	87	128.7	112.7	170	143.3
13 protan	130.7	91	94	170	158.7	128	149.3	170
14 protan	13.3	106.3	79.7	160.7	138.3	170	170	170
15 protan	35	103	58.7	123.7	96.7	148.3	170	170
16 deutan	129	126	158.3	170	139.7	142	170	170
17 monochr.	107.7	108.7	147	170	141.7	160	170	170
18 deutan	122.3	130.3	65	160	110	160	170	160
Mean	73.2	114.6	83.3	141.5	120.5	137.2	155.7	157
SD	49.6	27.6	44.3	31.3	28.8	24.5	23.6	18.3
Overall Mean	87.09	118.3	104.3	152.3	129.4	136.3	159.7	163.0
SD	42.8	27.2	39.4	24.9	26.2	26.8	17.7	14.2

Normal Colour Vision Subjects 1 to 9
Defective Colour Vision Subjects 10 to 18

D.O.C. - Current Marker Triangle Shape
Exp - Experimental Triangle Shape

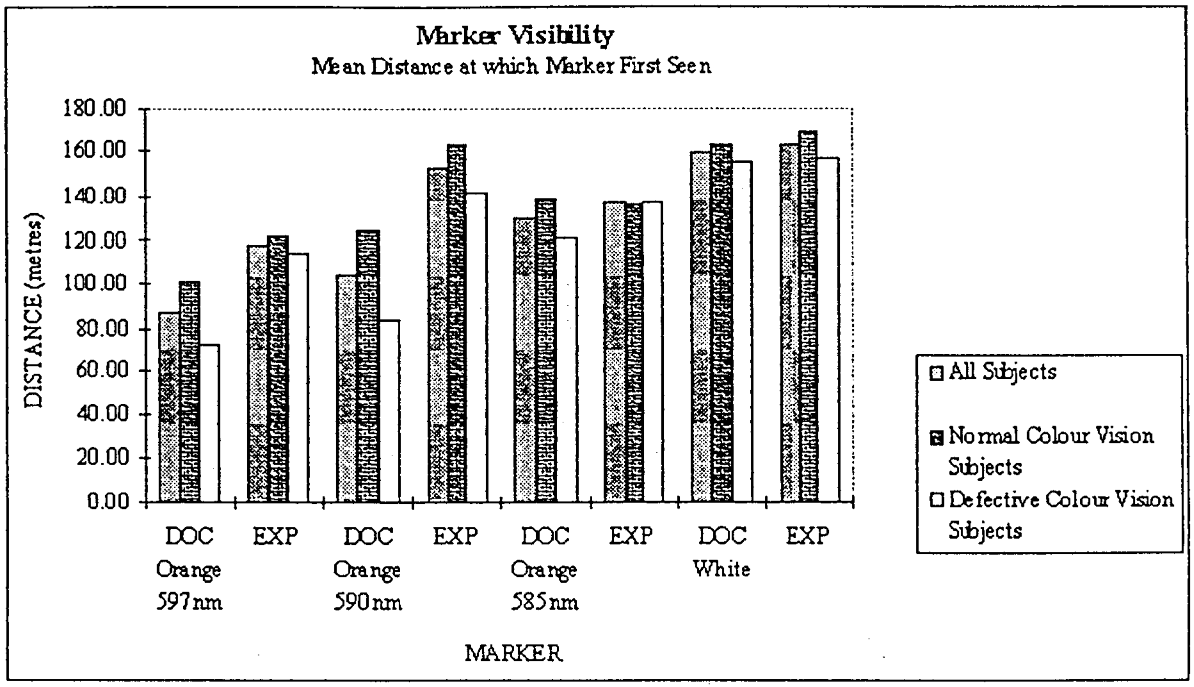


Figure 2 - *Marker Visibilitv, the eight markers are represented in 4 colours (597, 590nm, & 585nm and white), and 2 triangle shapes (D.O.C. height to base ratio 1.48:1, Experimental triangle with ratio 1:1)*

The 590 nm colour was found to be the most visible of the three orange hues in the" EXP" shape for both groups of subjects. The current D.O.C. 597 nm hue was the least visible, irrespective of marker shape.

From this result it was decided to utilise the "EXP" triangle configuration in Investigation Two to optimise visibility.

Investigation Two - Vinings Scenic Reserve

This was a 'real tramp' from the standpoint that none of the trampers were familiar with this track and so it was important that markers be located quickly, not just for the timing task but also to remain on the track.

Table 2 : *Marker Sighting Times (measured in seconds)*

SUBJECTS	**MARKER**			
	Orange 597nm	Orange 590nm	Orange 585nm	White
1	26.6	26.7	27.9	26.1
2	15.8	31.1	15.6	16.7
3	15.7	20	16.6	17.9
4	14.8	17.7	15.5	16.1
5	22.6	26.4	23.6	24.7
6	20.3	25.5	14.2	17.6
7	25.6	26.4	26.3	26
8	19	22	15.2	15.1
9	15.5	17.9	16.8	9.7
10	17	17.7	15.3	13.1
11	21.5	20.8	20.5	22.7
12	22.5	22	19.9	16.3
13	10.5	9.5	10.4	6
14	23	29.9	23.6	21.4
15	12.4	16.3	16.7	13.6
16	25.3	26.4	19.8	21.3
17	31.3	26.6	21.8	15.5
18	19.4	22.1	19.5	17.2
19	19.8	26	19.6	20.8
20	17.5	12.5	14.8	14
21	19.5	22.1	29.5	18.4
22	18.6	19.9	17.9	19
23	17.6	18	16.7	20.5
24	22.7	25.4	23.7	25.9
25	11.7	12	15	11.5
Mean	19.5	21.6	19.1	17.9
SD	4.9	5.6	4.7	5.1
26 protan	13.8	17.8	14.7	17.3
27 protan	23.5	17	13.7	20.1
28 deutan	18	21.5	20.8	20.2
29 protan	12.5	15.4	17.5	24
30 unclassified.	9.3	11.2	8.5	10.22
Mean	15.4	16.6	15	18.4
SD	5.5	3.7	4.6	5.1
Overall Mean	18.8	20.9	18.4	18
SD	5.1	5.6	4.8	5.1

Normal Colour Vision Subjects 1 to 25

Defective Colour Vision Subjects 26 to 30

Observers with norinal colour vision

The bush environment showed up the weaknesses of using white markers against forestation background, especially where there is lichen on the bark, or the trunks had variegated colouration. White was the least visible marker in the bush setting for observers with normal colour vision. However 590 nm was the most visible marker for this group. These results are summarised in Table 2 and graphed in Figure 3. The 590 nm marker was the earliest coloured marker seen (on average) by 16 of the 25 subjects. Only 5 subjects seeing the present D.O.C. coloured marker earlier than other markers. Interestingly, for 7 of the remaining 9 subjects who did not sight the 590 nm marker first, it was recorded as being their second most visible.

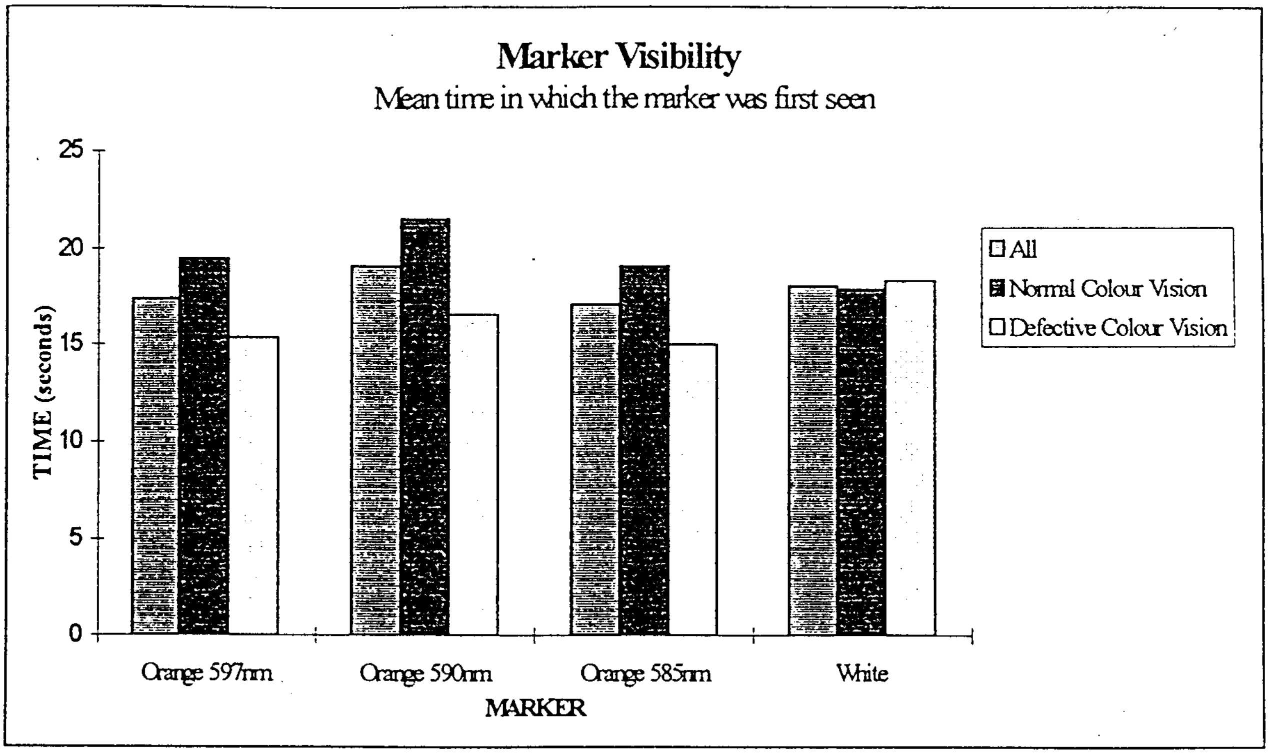


Figure 3 - *Marker sighting times, Four Markers (3 orange and white), matched for reflectance (approximately 42%) viewed against a bush/park background and fixed to tree trunks.*

Colour Vision Defective Observers

The C.V.D. subjects sighted the white marker ahead of the orange hues by a clear margin. However, the visibility of white for this group was only marginally better (3%) than the response of normal observers to the white marker. The visibility of each orange hue was approximately 20% less than the performance of the normal observers for each corresponding marker.

This result is not surprising because the person with a C.V.D. is not identifying markers on the basis of colour but on the basis of a brightness difference. Some volunteered that they were looking for the unique shape of the marker on a tree trunk. In contrast, the normal observer's task involves detection of the marker's novel colour.

DISCUSSION

White Marker

The loss of the white marker's relative superiority, for normal observers, in the second of the two investigations is not surprising. It demonstrates how important a novel or unique colour can be for persons who see colours normally, with normal colour vision, particularly when the background is not of uniform colour or illumination. As has already been mentioned, the C.V.D. subjects approach the task of detecting track markers using a different set of observer cues and it was expected that they would detect first the colour ('white') which they see to be the brightest. Colours which are equated for reflectance and purity for the normal observer will not appear to be of equal brightness to the C.V.D.

Colour

Observation of the coloured samples in Appendix III shows that there is actually very little apparent difference in colour between the three orange shades. Research using pure spectral colours, under ideal viewing conditions has shown that the "just discriminable difference" in this spectral region is 1 nm. The mixed colours, of about 80% purity, used in these studies are probably little more than two "just noticeable discriminable difference" steps apart, and yet their relative visibilities in the field are significantly different.

In the field trial, Investigation Two, the mean sighting times in Table 2 show that for normal observers the present D.O.C. (597 nm) colour required almost 10% more time to be located than the 590 nm marker. The Tukey-Kramer Multiple Comparisons Test showed that the mean time for the 590 nm marker was significantly different to the times for both other markers, 585 nm and 597 nin ($p<0.05$, dF = 3), and the white marker ($p<0.01$, dF = 3). By comparison, the 585 nm (a "yellower" orange) marker needed about 12% longer and the 'white' marker needed 17% longer, in relative terms.

For subjects with C.V.D.s the advantage of the 590nm marker over the present D.O.C. colouration was not as great. The present D.O.C. marker still required 7% more time to be located than the 590 nm marker. However, the small numbers of subjects with C.V.D.s mean that this figure is not as reliable. This fact is illustrated in the raw data of subject #27(Appendix VII) which shows they made a "chance" sighting of the 597nm marker # 8 at more than 5 times the study's average sighting interval. A more important observation is that the 590 rim marker was the first seen, on average, by 3 of the 5 CN.D.s.

There are two visual factors which would influence conspicuity of markers in the 'orange' region of colours. The first visual factor is that colours near 600 nm (redder) have a lower luminous efficiency (Figure 4) than at 555 nm (green-yellow), for all subjects. This means that 585 nm is perceived to be brighter than 590 or 597 nm.

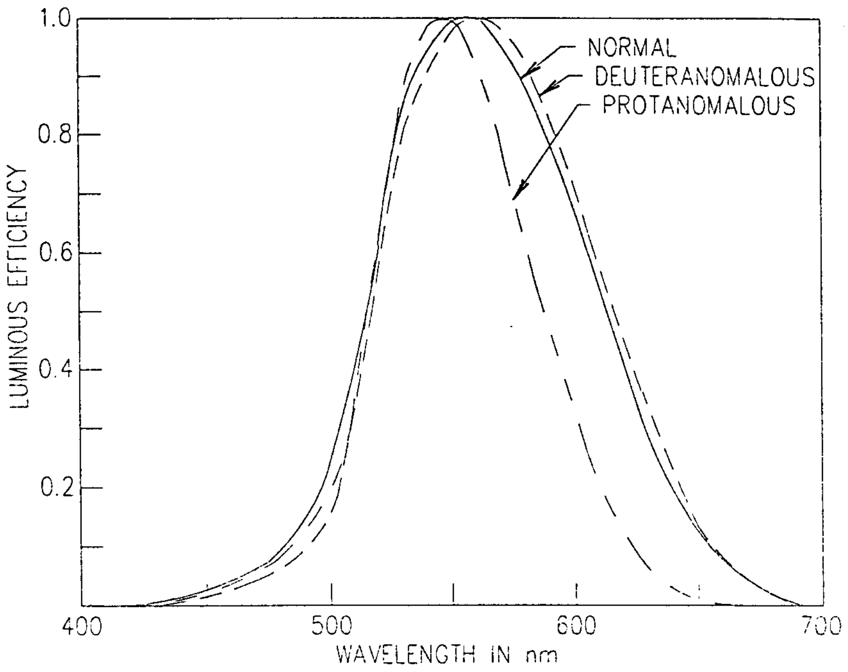


Figure 4: *Mean luminous efficiency curves for the normal trichromat, the protanomalous and the deutanomalous observer (from Wright, 1946)*

The second visual factor is that colours near 585nm(yellower) appear less saturated (less vivid) for the normal observer(Figure 5). For the track markers in this study this means that the 597nm colour (current D.O.C. colour) has greater saturation (is more colourful) than either 590 or 585nm.

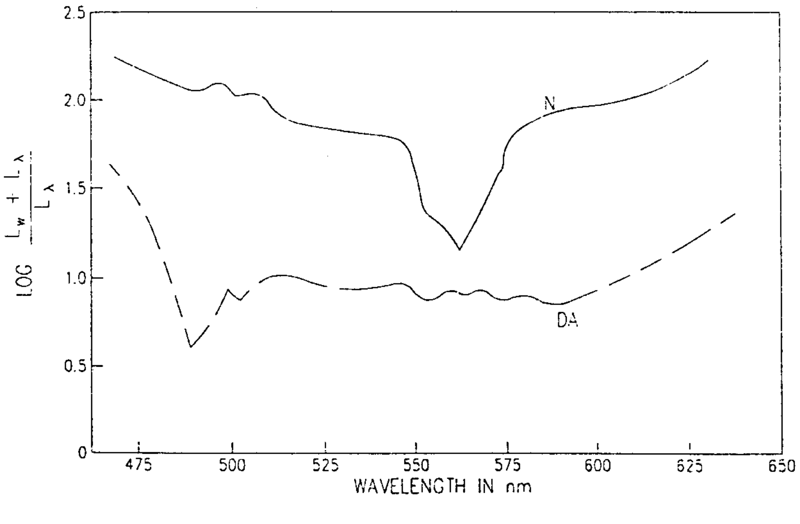


Figure 5 - *Chapanis' Measurements of the Intrinsic Saturation of Spectrum Colours*

A "trade-off" between these two factors (loss of brightness if made more red, loss of vividness if made more yellow) could possibly explain why the 590 nm colour outperformed the 585 nm and 597 nm colours, which are positioned either side of it in the spectrum. This is presented in graphed form in Appendix VI. For observers with C.V.D.s there is little if any change in the vividness (colourfulness) of orange colours as they are made more yellow, as they do not appear vivid at all. This would presumably explain why their Vinings Reserve results "mirrored" the normal observers, but lagged them by 20%.

Observers with C.V.D.s do however see the loss of brightness as the orange is made more red so that a change towards a more yellow colour will benefit these people.

Shape and Size

During Investigation One in the Domain Study the more compact "EXP". triangle was a significant 30.2% more visible than the "D.O.C". shape, for the 590nm marker colour(Figure 2). This suggests that there could be some considerable advantage gained in altering the dimensions of the marker, especially for the C.V.D. s (Figure 6).

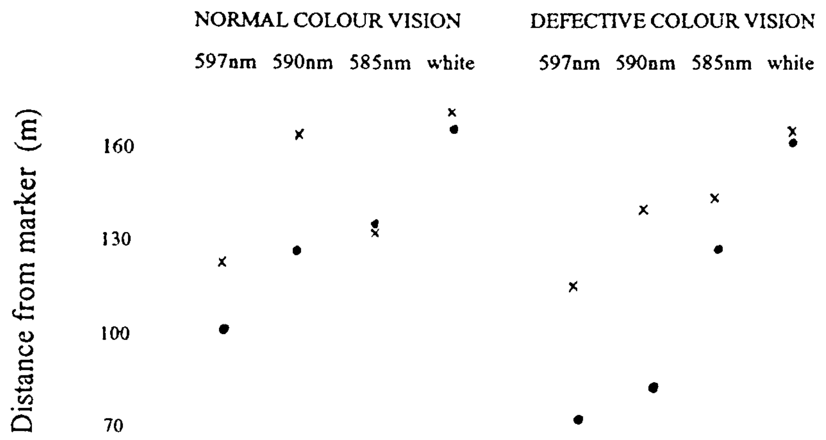


Figure 6 - *Comparison of the the visibility of the D.O.C marker(filled dot) and the EXP marker(cross) shapes presented in 4 colours (597 mn, 590nm, 585nm and white) for the observers with normal and defective colour vision.*

This result can be explained by the interaction which occurs between perimeter length and surface area of a figure. For targets of equal area, and similar shape, those with a longer perimeter are generally less visible. In this case the present D.O.C. marker shape with its longer perimeter and more acute apex would be predicted to be less visible. A simple demonstration is included in Appendix VII to illustrate the effect of this interaction between perimeter length and surface area.

Performance of Colour Vision Defectives

The averaged results for these observers obscure the excellent observation times achieved by some of these trampers. Figure 7 presents a scatterplot of the data from Table 2 and it shows that the C.V.D.s were by no means the worst observers on the track in the second investigation. On the other hand, some of them returned excellent sighting times.

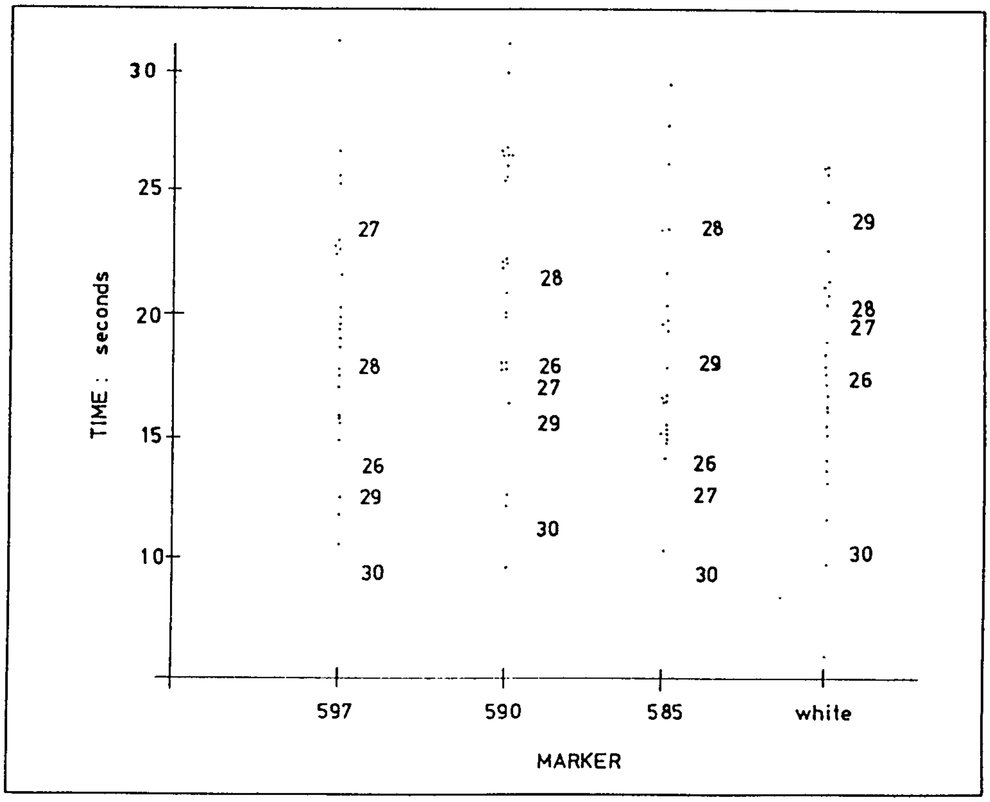


Figure 7 *Individual subjects marker alignment times. Scatterplots of the subjects averaged data from Table 2. The dots represent the normal observers(Nos. 1-25) results while the numbers on the graph indicate the colour vision defectives(Nos. 26-30). A longer sighting time implies superior perfonnance.*

The important conclusion from this study is the improved marker visibility for the C.V.D.s when the present D.O.C. marker colour is moved slightly toward yellow.

In Investigation One visibility for the C.V.D.s was increased 13.8% by simply altering the marker colour from 597nm to 590nm. When the shape of the marker was also altered, to a more compact triangle with no change in surface area, marker visibility was enhanced by a dramatic 93.3%!

Four of the 5 C.V.D.s in Investigation Two showed large individual improvements to their visibility times when the marker colour was altered. Their increase in visibility for locating a 590nm coloured marker, compared to the present 597nm coloured marker, ranged from 19.4 to 29%!

Results for subject #27 are not included in this range, for the reason mentioned on page 9.

CONCLUSIONS

The principal criticism of the present D.O.C. marker is that people with colour vision defects (C.V.D.s, 8% of the male population) have difficulty locating it in the bush situation. This study shows that this indeed occurs and recommends some changes to enhance the marker visibility for this group of trampers in particular, without unduly compromising the marker's environmental conspicuousness.

The Department's marker is a vast improvement over any previous marker in terms of its colour, size, shape and reflectance. This report has shown how its visibility can be improved in the bush setting by at least 11% for normal observers and by at least 19-29 % for C.V.D.s by including a fairly minor colour alteration.

RECOMMENDATIONS

It is the suggestion of this report that the following recommendations be considered:

Colour

Utilise a colour with dominant wavelength 590 nm(Appendix II) with C.I.E. co-ordinates X = 0.529, Y = 0.396 (standardised under D65 lighting, and mixed from RED and YELLOW primary dye pigments, rather than the present mixture derived using red and orange "primaries").

Purity

Consider increasing this from the present 83%. However, this should not approach 90% or it would coincide with the Protan's(red-weak C.V.D.) confusion locus(Appendix II). This would mean that the 590nm colour would then be confused by this group of C.V.D.s with a wide variety of higher purity reds, oranges, yellows and greens.

Reflectance

Consider some of the options for enhancing surface reflectance above the current 0.4 level.

Marker Shape

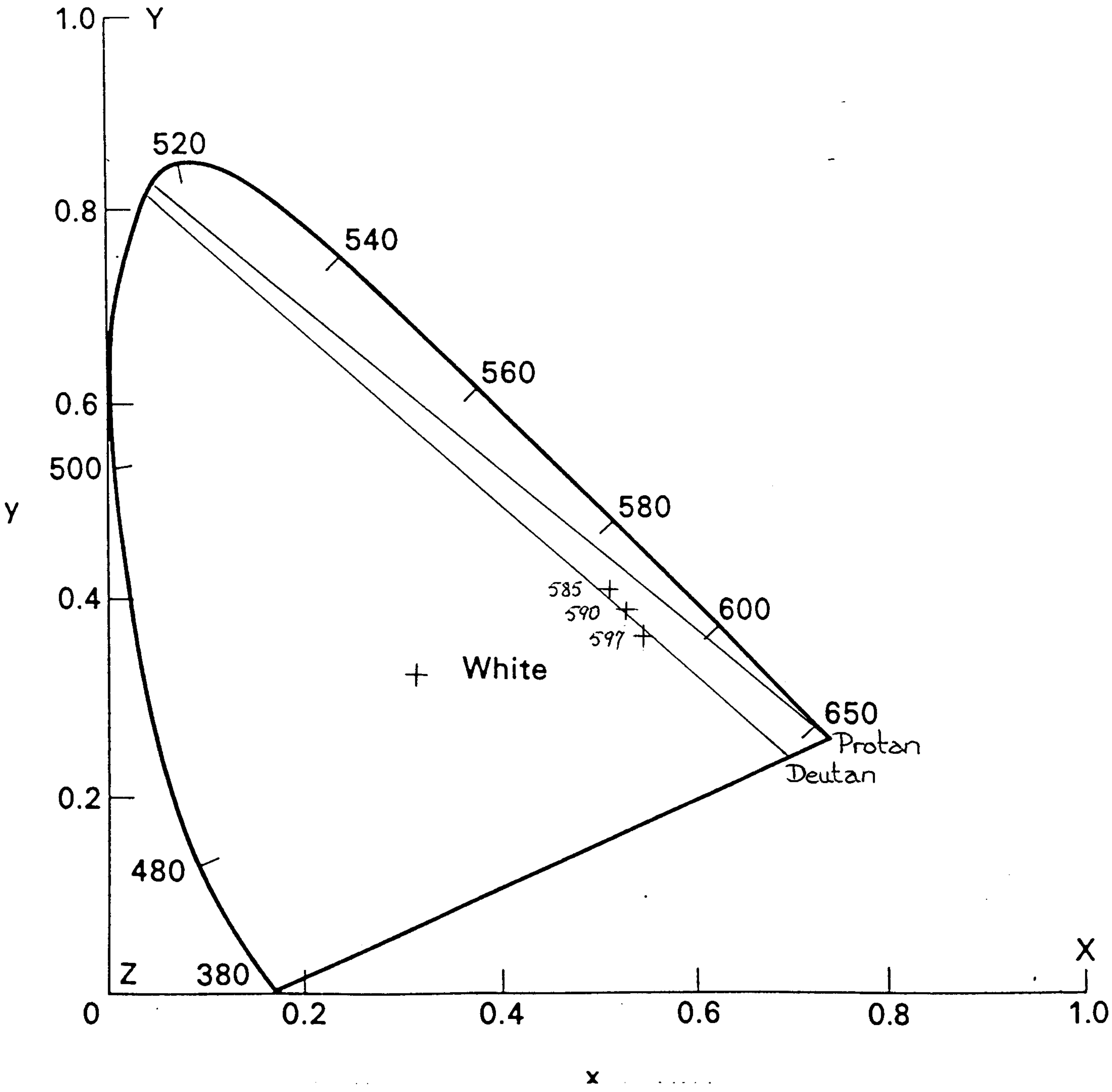
Increase the base to height ratio from the present 0.65 quotient to something nearer the 1.00 "EXP" shape used in this study. For example, if the existing mould die-set could have the marker base dimension opened up to 89mm this would increase the ratio to 0.81.

APPENDIX I - C.I.E. Co-ordinates of the marker colours used in this study.

	Dominant Wavelength	C.I.E. Co-ordinates X	Y	Purity
White		0.3159	0.3329	1.18%
Orange	597nm	0.5474	0.3691	83.47%
Orange	590nm	0.5449	0.396	83.39%
Orange	585nm	0.5152	0.4164	83.57%

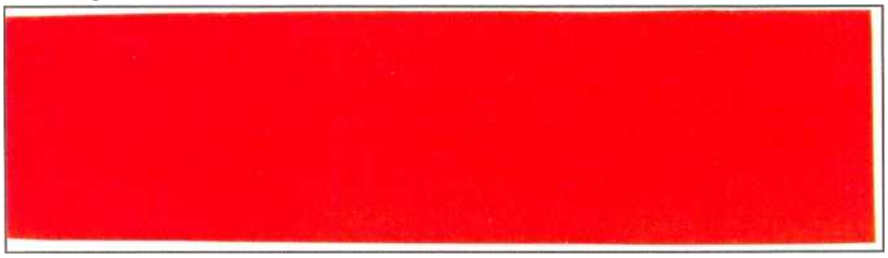
Measurements made using standard daylight (D65)

APPENDIX II - C.I.E. Chromaticity Diagram, showing the marker colours and the closest confusion loci for the Protan(red weak) and Deutan(green weak) colour vision defectives.

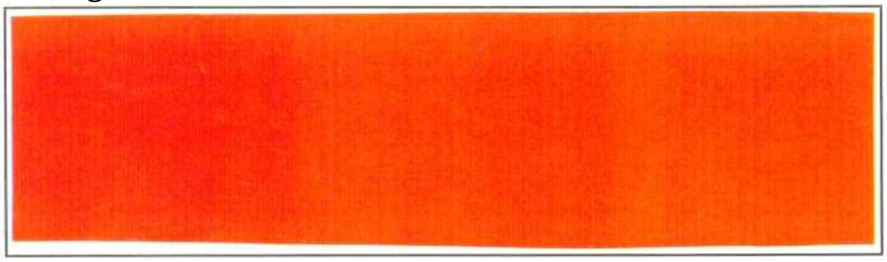


APPENDIX III - Photocopies of the marker colour samples used in this study.

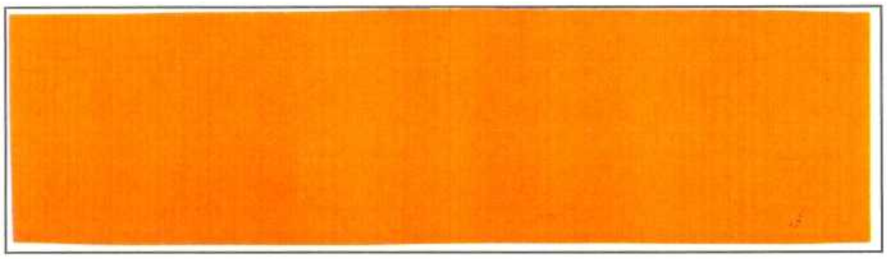
Orange 597nm



Orange 590nm



Orange 585nm



APPENDIX IV - Data from Investigation One: Auckland Domain.

Raw Data - Distance in metres
Trial One - Auckland Domain

Subject	Orange 597nm DOC				Exp				Orange 590nm DOC				Exp			
1	135	145	160	146.7	170	170	120	153.3	170	160	133	154.3	170	170	170	170
2	76	79	80	78.3	94	119	123	112	97	141	170	136	170	170	170	170
3	100	100	86	95.3	92	108	119	106.3	97	121	137	118.3	170	170	170	170
4	63	98.5	80	80.5	80	105	115	100	106	134	110	116.7	155	155	160	156.7
5	34	29	150	137.7	110	130	130	123.3	110	130	130	123.3	170	170	170	170
6	65	60	81.5	68.8	115	105	145	121.7	106	134	139	126.3	140	170	159	156.3
7	60	70	83	71	80	80	73	77.7	82.5	88	91.5	87.3	131	170	142	147.7
8	82	95	97	91.3	170	170	170	170	97	150	170	139	170	170	170	170
9	135	115	148	133	140	115	145	133.3	140	125	115	126.7	145	160	170	158.3
10 deutan	12	15	18	15	75	95	40	70	30	50	30	36.7	104	109	117	110
11 deutan	74	50	77	67	118	135	135	129.3	90	77	73	80	115	130	120	121.7
12 protan	16	50	50	38.7	170	160	170	166.7	15	36	41	30.7	87	90	84	87
13 protan	118	144	130	130.7	65	105	103	91	127	80	75	94	170	170	170	170
14 protan	7	15	18	13.3	75	121	123	106.3	75	82	82	79.7	165	155	162	160.7
15 protan	30	40	35	35	97	90	122	103	65	45	66	58.7	110	131	130	123.7
16 deutan	133	129	125	129	88	140	150	126	135	170	170	158.3	170	170	170	170
17 monochr	135	93	95	107.7	106	110	110	108.7	170	148	123	147	170	170	170	170
18 deutan	107	130	130	122.3	145	122	124	130.3	70	60	65	65	140	170	170	160

Distances: first, second, third & mean measurements

Orange 585nm DOC				Exp				White DOC				Exp			
160	170	170	166.7	167	170	170	169	170	170	170	170	170	170	170	170
142	145	150	145.7	127	158	123	136	147	170	170	162.3	170	170	170	170
150	150	133	144.3	105	158	132	131.7	147	170	170	162.3	170	170	170	170
142.5	141	82	121.8	94	64	90	82.7	140	147	160	149	155	163	164	161
134	129	150	137.7	95	170	140	135	138	150	161	149.7	170	170	170	170
65	130	122	105.7	115	79	90	94.7	170	170	170	170	170	170	170	170
95.5	131.5	107	113.3	119	154.5	142.5	138.7	170	170	170	170	170	170	170	170
170	150	155	158.3	170	170	170	170	170	170	170	170	170	170	170	170
155	140	163	152.7	150	162	170	160.7	170	170	170	170	170	170	170	170
65	44	85	64.7	100	110	110	106.7	112	115	123	116.7	104	134	125	121
118	101	100	106.3	115	105	100	106.7	115	115	115	115	120	170	125	139
147	117	122	128.7	108	123	107	112.7	170	170	170	170	110	150	170	143
136	170	170	158.7	85	155	144	128	160	155	133	149.3	170	170	170	170
134	129	152	138.3	170	170	170	170	170	170	170	170	170	170	170	170
100	100	90	96.7	144	155	146	148.3	170	170	170	170	170	170	170	170
143	106	170	139.7	116	170	140	142	170	170	170	170	170	170	170	170
170	103	152	141.7	140	170	170	160	170	170	170	170	170	170	170	170
90	110	130	110	170	150	160	160	170	170	170	170	140	170	170	160

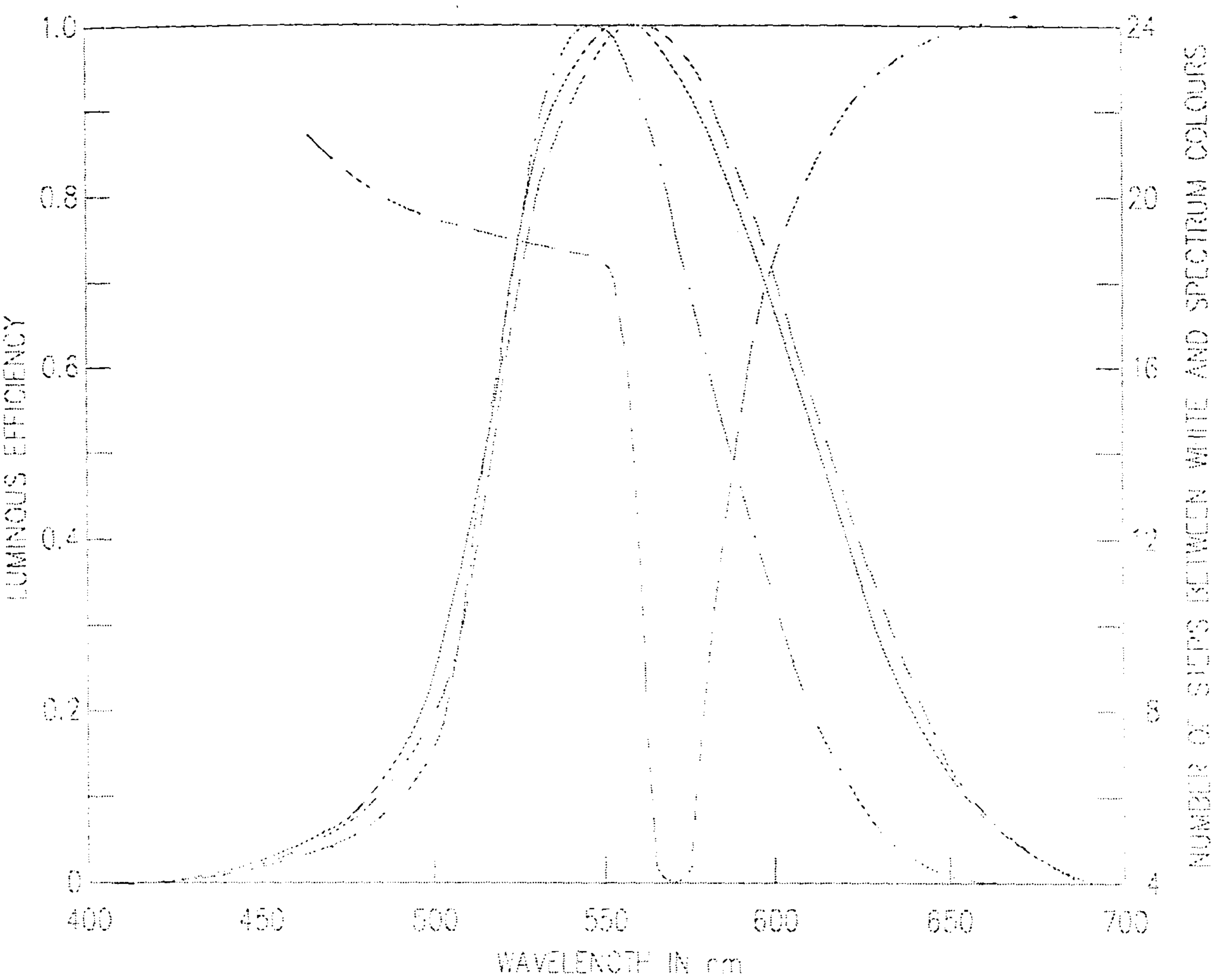
APPENDIX V - Data from Investigation Two: Vining's Scenic Reserve, Hunua Ranges.

Raw Data - Time in seconds
Trial Two - Vining's Scenic Reserve

Subject	Orange 597nm											Orange 590nm										
	1	2	3	4	5	6	7	8	9	10	Mean	11	12	13	14	15	16	17	18	19	20	Mean
1	50	47	24	19	22	6	28	16	32	22	27	32	40	28	26	7	19	30	29	24	32	27
2	25	41	15	14	0	3	20	9	19	12	16	40	38	116	23	0	11	23	21	20	19	31
3	28	20	20	15	22	2	15	14	3	18	16	21	33	21	21	21	15	20	16	19	13	20
4	25	21	12	14	14	4	17	8	18	15	15	30	24	18	19	16	14	13	16	17	10	18
5	30	41	25	21	24	2	25	14	22	22	23	30	39	24	34	16	23	26	28	20	24	26
6	34	24	15	15	17	3	49	3	20	23	20	53	46	21	30	15	14	18	21	20	17	26
7	0	51	25	21	30	26	36	18	26	23	26	31	14	33	44	21	20	31	27	22	21	26
8	20	40	15	25	21	0	24	10	15	20	19	38	39	23	21	13	14	24	18	18	12	22
9	21	25	15	15	14	3	30	10	4	18	16	35	25	14	16	11	13	16	16	22	11	18
10	36	22	15	13	13	2	32	7	13	17	17	23	41	19	18	4	8	19	21	13	11	18
11	34	17	21	22	24	8	28	11	26	24	22	32	28	21	27	8	12	16	18	26	20	21
12	26	38	16	23	26	10	25	13	24	24	23	22	54	21	21	10	19	17	21	20	15	22
13	0	13	11	11	9	8	10	9	9	25	11	8	7	7	11	5	10	15	11	9	12	10
14	64	14	19	17	12	6	37	12	26	23	23	41	59	18	27	26	23	36	31	23	15	30
15	16	12	21	13	17	1	20	3	8	13	12	22	23	17	23	3	12	13	15	19	16	16
16	53	35	21	18	22	7	38	13	29	17	25	33	46	20	28	30	14	29	22	18	24	26
17	41	47	23	22	26	2	33	17	41	61	31	30	42	49	27	23	15	29	0	19	32	27
18	23	51	18	19	2	2	22	11	28	18	19	28	19	18	24	10	20	10	56	15	21	22
19	47	17	13	18	17	7	17	15	20	27	20	53	26	10	20	11	20	46	21	27	26	26
20	39	15	20	19	25	0	19	6	20	12	18	13	0	11	21	13	13	7	17	12	18	13
21	21	26	18	24	24	7	29	12	19	15	20	16	22	23	24	33	21	18	29	22	13	22
22	15	30	18	13	19	5	20	13	36	17	19	35	14	21	16	13	14	21	22	25	18	20
23	31	32	21	20	5	0	30	8	18	11	18	38	27	18	30	2	14	10	17	12	12	18
24	40	32	16	22	21	6	27	12	22	29	23	36	37	16	24	26	21	27	21	23	23	25
25	12	13	10	11	13	3	11	10	20	14	12	16	15	8	14	9	10	16	8	15	9	12
26 protan	32	6	17	15	9	5	20	5	18	11	14	62	15	19	16	6	8	15	9	15	13	18
27 protan	37	27	18	14	24	4	12	66	9	24	24	29	13	16	14	12	16	13	28	20	9	17
28 deutan	50	22	13	17	15	3	20	12	11	17	18	21	31	18	25	14	22	34	20	17	13	22
29 protan	37	16	5	9	7	1	17	10	10	13	13	20	14	9	22	6	16	15	22	15	15	15
30 unclass.	15	11	9	6	9	11	12	3	9	8	9	17	7	14	16	1	9	3	14	19	12	11
Mean for each marker	29	26	17	17	17	5	24	12	19	20	19	30	28	22	23	13	15	20	20	19	16	21

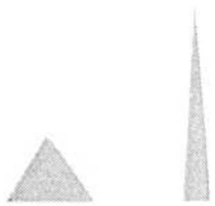
Orange 585nm											White									
21	22	23	24	25	26	27	28	29	30	Mean	31	32	33	35	36	37	38	39	40	Mean
41	17	23	35	25	14	31	23	21	49	28	36	15	48	18	13	41	35	20	19	27
30	13	0	10	19	14	21	3	11	35	16	31	0	39	8	26	5	27	0	31	19
24	15	0	28	19	21	27	2	11	19	17	28	15	35	13	18	3	25	8	9	17
24	11	5	23	17	14	23	14	4	20	16	26	8	20	49	11	5	17	7	3	16
31	17	21	23	25	21	22	22	15	39	24	34	15	15	20	18	10	##	15	20	27
7	2	4	0	26	16	14	30	15	28	14	23	21	6	8	21	37	28	12	20	20
29	20	14	45	39	33	20	24	21	18	26	37	27	21	31	31	10	37	13	26	26
27	9	9	9	26	15	1	18	21	17	15	29	5	11	8	18	9	33	9	16	15
25	12	14	16	12	17	22	15	11	24	17	22	1	5	12	6	4	23	11	13	11
23	10	7	26	16	11	7	8	23	22	15	28	14	18	3	11	11	21	9	16	15
29	10	12	37	16	22	28	19	11	21	21	30	16	45	20	30	0	22	11	27	22
35	20	7	15	30	17	21	16	9	29	20	22	19	18	10	18	28	22	14	12	18
22	5	7	13	7	9	9	8	10	14	10	7	8	8	4	8	2	7	7	5	6
37	17	13	29	21	24	28	23	13	31	24	33	20	20	18	27	8	41	11	36	24
36	5	8	25	12	18	20	10	13	20	17	16	9	22	16	12	5	17	11	7	13
31	18	18	14	9	19	21	21	18	29	20	27	15	26	12	17	15	41	12	36	22
34	19	10	28	19	15	19	22	14	38	22	28	12	7	0	21	5	39	14	29	17
35	14	0	8	28	21	27	18	22	22	20	31	17	14	2	25	9	33	10	21	18
37	13	6	10	20	22	20	20	16	32	20	15	15	10	37	23	12	44	18	34	23
34	13	11	6	18	12	21	12	6	15	15	30	18	19	12	9	0	19	8	25	16
34	12	20	57	24	27	30	23	23	45	30	28	16	13	10	20	6	35	22	10	18
22	9	14	14	15	12	23	12	27	31	18	29	18	36	9	14	11	26	12	20	19
33	17	7	13	19	18	17	4	10	29	17	25	12	38	7	23	3	14	9	34	18
33	12	21	20	18	27	28	20	23	35	24	31	6	39	15	26	29	33	14	38	26
14	11	16	15	19	16	19	15	10	15	15	10	13	12	6	15	6	14	18	10	12
0	10	7	33	16	20	17	15	6	23	15	28	13	20	23	19	11	17	12	30	19
22	16	6	19	0	13	8	8	21	24	14	28	14	25	19	17	10	32	26	30	22
35	16	9	40	22	14	16	16	16	24	21	35	14	28	17	17	9	29	10	21	20
25	7	12	8	17	19	31	24	11	21	18	31	25	26	12	22	14	49	17	17	24
14	8	11	14	8	11	0	16	3	0	9	11	11	8	3	6	13	19	9	0	9
27	12	10	21	19	18	19	16	14	25	18	26	14	21	14	18	10	30	12	21	18

APPENDIX VI - Luminous efficiency(Figure 4) versus saturation sensitivity(Figure 5).



This diagram shows the graph of luminous efficiency superimposed on the graph of intrinsic saturation. The latter is determined as the number of just perceptible steps between white and spectrum colours using a double observation colourimeter. The "trade-off' zone between these two psychophysical variables can be seen to occur in the region of 600nm.

APPENDIX VII - A demonstration of the interaction between perimeter length and surface area.



These two triangles have approximately the same area(approx. $45mm^2$), but the squatter figure has a perimeter length of about 31 mm while the taller figure's perimeter length is nearer 55mm. If these triangles are viewed from a distance of about 10 - 15 metres, the squatter figure, with the shorter perimeter length, appears the more visible.