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A potential new colour vision assessment tool for young children

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Abstract

Aim: **There are many colour vision tests available that detect, classify and grade colour deficiency for adults. Testing colour vision in older children is possible using the same tests but very young children may not yet be confident in identifying pictures and numerals, or may not understand tracing coloured pathways. This pilot study was designed to assess whether Lego® bricks, which are available in many waiting areas, could be applied to detect colour vision deficiency.**

Methods: **Two groups of 10 male subjects (age 18–32 years) were recruited. One group were colour normal (CVNorm) and 10 were aware of a colour defect (CVDef). Each group completed a standard colour vision assessment consisting of the anomaloscope, Ishihara pseudo-isochromatic plates and D-15 saturated caps. The CVNorm and CVDef groups were required to match Lego® bricks of the same colour from a tray containing bricks of many colours within a light box using standard illuminant C. Different numbers of the test bricks (red, green, blue, yellow and beige) were randomly selected. Black, light green, white and orange bricks were added as distraction bricks. In a given time limit subjects had to select the bricks of a colour chosen by the assessor, and were scored for incorrectly chosen or missed bricks. The task was repeated under fluorescent and incandescent illumination.**

Results: **CVNorm subjects had zero errors matching the bricks under all three illumination conditions. The CVDef group consisted of 9 dichromats (6 deuteranopes, 3 protanopes) and 1 deuteranomalous trichromat. Some CVDef subjects made one or two errors but in general many completed the task without making any errors. There was no statistical difference between the groups under any of the three illumination conditions.**

Conclusion: **Conventional Lego® bricks did not detect colour-matching problems in adults previously identified with severe colour deficiency and therefore cannot be recommended as a single test for paediatric colour vision examination.**

Key words: Anomaloscope, Colour vision, Farnsworth D15 test, Ishihara plates

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Introduction

Colour vision examination is a routinely performed test within eye clinic consultations. To detect pathology or identify congenital colour vision deficiencies (CCVD) an assortment of tests have been developed to assist the practitioner in understanding their patients' colour perception. A review by Holmes[1] outlined the use and interpretation of common colour vision tests, and how to advise patients on the basis of the results. However, the available tests within eye clinic consultation rooms usually do not serve young or preverbal children.

During childhood development, colour is frequently used in education. For example, in primary schools colour may be used to put children into different groups, or parts of the classroom may be sectioned according to colour. Team games have opposing players wearing different colours. The importance of colour is extended in secondary education in subjects such as chemistry, geography, biology and geology. Although there is no evidence that educational achievement is lower in the overall population with a colour vision defect,[2] an individual child may be handicapped by a colour vision deficiency and feel anxious or different. In addition many parents with or without a family history of colour deficiency are concerned about their child's colour perception. The introduction of pseudo-isochromatic plates utilising shapes (Hardy Richmond Rand Plates) or pictures (Colour Vision Test Made Easy) have shown inaccurate responses in children who actually have normal colour vision[3] and these tests are only likely to be found in specialised clinics. The easy availability of a reliable colour vision test may speed detection of a defect which might allow the child, their carers and teachers to adopt appropriate strategies, and ensure appropriate career advice is given.[4,5]

A colleague of the authors observed that as many eye clinic practices have a play area for children waiting for an assessment, in which a common toy is Lego® bricks of various colours, it may be possible to use these bricks to test the ability of young children to identify similar-coloured objects. The aim of the test would be to indicate whether the child had difficulties matching colour or whether the task was completed relatively easily. Any observed difficulties would alert the parents and would be followed up with detailed diagnostic tests when the child was older.

The aim of this study was to investigate the validity of using Lego® bricks to distinguish adults with previously-diagnosed colour deficiency from those with normal colour vision. Colour deficiency is categorised

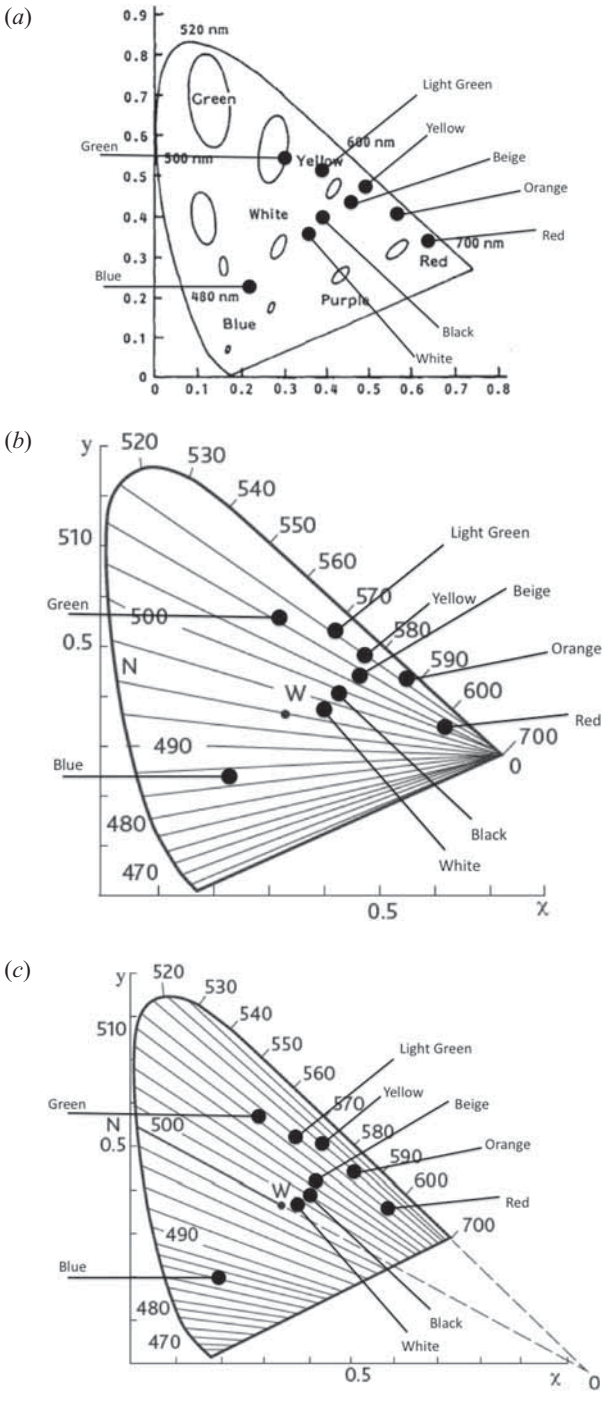

Fig. 1. (*a*) The *x* and *y* coordinates for Lego® bricks plotted against a CIE diagram for estimated colour confusion amongst normal subjects. Visible wavelengths with different *x*, *y* coordinates may be perceived as similar if within an ellipse of colour confusion. The *x*, *y* coordinates for each Lego® brick were outside each ellipse and hence no colour confusion was anticipated for subjects with normal colour vision. (From Margrain *et al.*[7]) (*b*) The *x* and *y* coordinates for Lego® bricks plotted against a CIE diagram for estimated colour confusion amongst protan subjects. Wavelengths with *x*, *y* coordinates within the same zone are confusable due to missing/abnormal L photopigment. For example distinguishing between red and black bricks was predicted to be a possible confusion for protan dichromats as the coordinates are within the same zone. (From Holmes[1]) (*c*) The *x* and *y* coordinates for Lego® bricks plotted against a CIE diagram for estimated colour confusion amongst deutan subjects. Wavelengths with *x*, *y* coordinates within the same zone are confused due to missing/abnormal M photopigment. For example distinguishing between green and light green or between yellow and orange Lego® bricks were possible causes of colour confusion for deutan dichromats. (From Holmes[1])

by the functioning of the photopigments that mediate colour vision. If two out of three photopigments were present the participant was defined as dichromatic. When three photopigments were present but one had an abnormal spectral sensitivity, anomalous trichromacy was present. Protan deficiency is related to missing/abnormal L photopigment, whilst missing/abnormal M photopigment is referred to as deutan deficiency. If known dichromats or anomalous trichromats were shown to be unable to discriminate Lego® bricks appropriately, then there would be potential to further investigate the test in young children.

Before the test, participants were instructed to construct a tower of Lego® using bricks of all one colour, which matched a brick chosen by the examiner. It was hypothesised that those with normal colour vision would have no difficulty constructing such a tower whilst the subjects with known congenital red–green colour deficiencies would make errors.

A preliminary investigation used a Photo Research PR-650 Spectrascan Colourimeter (PhotoResearch, Chatsworth, CA, USA) to determine the spectral reflectance of the full range of Lego® brick colours. The *x* and *y* coordinates were plotted onto colour confusion zones represented on the 1931 Commission Internationale de l'Eclairage (CIE) diagram. The CIE diagram is a common way of specifying colour based on three primaries of photopigments.[6] Colours with coordinates towards the centre of the diagram are considered to be desaturated; saturation increases towards the outer edges. The reader is referred to Holmes[1] (pp. 167–169) for a description of colour confusion zones. An individual with normal colour vision is expected to show colour confusion for some wavelengths, which are demonstrated by ellipses within Fig. 1*a*. The *x*, *y* coordinates for the Lego® bricks did not fall within the colour confusion ellipses for normal colour vision and therefore participants with normal colour vision were not expected to demonstrate any confusion with the Lego® task. Individuals with colour confusion are represented by Fig. 1*b* and *c*. The CIE diagram is shown with parallel lines that compose the colour confusion zones. Any colours lying within these zones appear identical to a protanope (Fig. 1*b*) or to a deuteranope (Fig. 1*c*). For example, blue does not fall within the colour confusion zone for protan or deutan and is considered not to contribute to difficulty in completing the Lego® task. By comparison when subjects were asked to complete a tower using bricks of a colour that was within the colour confusion zone (i.e. black or red for protan (Fig. 1*b*) and orange or light green for deutan (Fig. 1*c*) it was predicted they would make more errors. The prediction was that the red–green defective subjects when asked to use red, green or brown bricks would make a tower of a mixture of these three colours, or perhaps just show a red/brown confusion. Although yellow was a potential colour confusion with red and green, these bricks reflect more light and it was predicted that subjects would avoid confusion by using the luminance cue. When blue was the chosen colour, the red–green defectives should be able to complete the task correctly.

Although it is important to conduct colour-matching tasks under standard illumination, this may not be

Table 1. Inclusion and exclusion criteria for the CVNorm and CVDef subjects

Inclusion	Exclusion
Male aged 18–50 years	Delayed cognitive processing
Normal colour vision *or* known colour deficiency	Aged-related vision changes
Visual acuity <0.1 logMAR	Ocular pathology
Log contrast sensitivity >1.65	Congenital achromatopsia

available in many assessment rooms. Therefore the new test was evaluated under different types of room illumination conditions to determine whether the results were robust.

Methods

All procedures followed the tenets of the Declaration of Helsinki. The research methodology was approved by the University of Manchester Committee on the Ethics of Research on Human Beings. Full explanations of the purpose and nature of the study were given and written consent obtained from all subjects.

A cohort of 10 colour vision normal (CVNorm) and 10 colour vision deficient (CVDef) young male adults were recruited via local advertising. The inclusion criteria are given in Table 1. All subjects attended a single session and received expenses.

Preliminary assessment

Visual acuity

The logMAR chart (Test Chart 2000, Thomson Software Solutions, Hatfield, Herts, UK) was tested at a distance of 6 metres with standard room illumination and acuity was measured monocularly. The right eye was assessed first, with spectacle correction if necessary. Subjects were excluded if their vision measured less than 0.1 logMAR units with spectacle correction. Subjects were encouraged to proceed as far down the chart as possible and were scored for each correct letter. Each letter correctly identified was given 0.02 log units credit. Good visual acuity reduced the possibility of including subjects with acquired colour deficiencies that are associated with impaired retinal function.

Contrast sensitivity

The Pelli–Robson chart (Clement Clarke International, Essex, UK) was used at a distance of 1 metre under recommended illumination conditions. Subjects were given 0.05 log units credit for every letter correctly identified.[8] There was no minimum contrast sensitivity required to participate in the study.

Nagel anomaloscope

The subject viewed through the eyepiece of the anomaloscope after adaptation to the Trendelenberg screen on the front panel. The red–green ratio and yellow dials were randomly altered and the subject was asked to match the upper and lower halves of the circle until they appeared to match and form a continuous circle. The subject was allowed to control the luminance of the yellow field whilst the examiner set the red–green ratio at random predetermined ratios from 0 to 70 in steps of 10 units. The subject was asked whether it was possible or not possible to match the luminance of yellow with the red–green ratio. The test was carried out with each eye in turn/monocularly, with the right eye tested first. A very narrow matching range with a typical mid-point characterised the CVNorm subjects. Anomalous trichromats had a displaced mid-point and wider matching range. Dichromats accepted a matching range that covered the complete spectrum of red–green ratios, by varying only the luminance control as appropriate.

Standard colour vision assessment

All colour vision tests were administered under standardised illumination in binocular conditions with the subject wearing appropriate refractive correction. A light box simulated the 'natural daylight of afternoon northern sky light in the Northern Hemisphere', referred to as standard illuminant C (Multi-Light, Berks, UK). Colour temperature was 6774K and illumination was at least 250 lux. The manufacturer's recommended field of view was used and cognitive factors were minimised by using standard instructions.

Ishihara pseudo-isochromatic plates

The plates were held 75 cm away from the subject by the examiner, perpendicular to their line of sight. The subject was instructed: 'On each page you may see a number or you may not see anything. Tell me what you see as I turn the page'. Each page was turned after about 4 seconds of viewing. The first 17 pages of the 24-plate edition were used. The total number of errors was recorded.

D-15 grading test

The caps were removed from the box and placed randomly within the light box. The subject was instructed to 'arrange the caps in order according to colour, starting with the cap most similar to the pilot cap'. Test distance was approximately 50 cm. Subjects were given as much time as required. Their sequence was recorded using the semi-circular recording chart. Major errors that crossed the circle entirely were counted and the number and axis of crossings determined the severity and type of the subject's colour deficiency respectively.

Lego brick assessment

An unequal number of red, green, blue, beige and yellow bricks were used, to minimise learning effects. The task commenced with the assessor choosing a brick of a particular colour and asking the subject: 'Make a tower using all the bricks on the table that look exactly the same as this one; make sure you include them all.' A 20 second time limit was applied to complete each tower, monitored by the assessor. Error scores were given for incorrect colours used in the construction of the tower and for bricks of the correct colour that were left unused. For example, if 9 green bricks should have been used in the test and the subject selected 5 green bricks and 3 bricks of other colours then the error score was 4 (for the unused bricks that were not chosen) plus 3 (for the

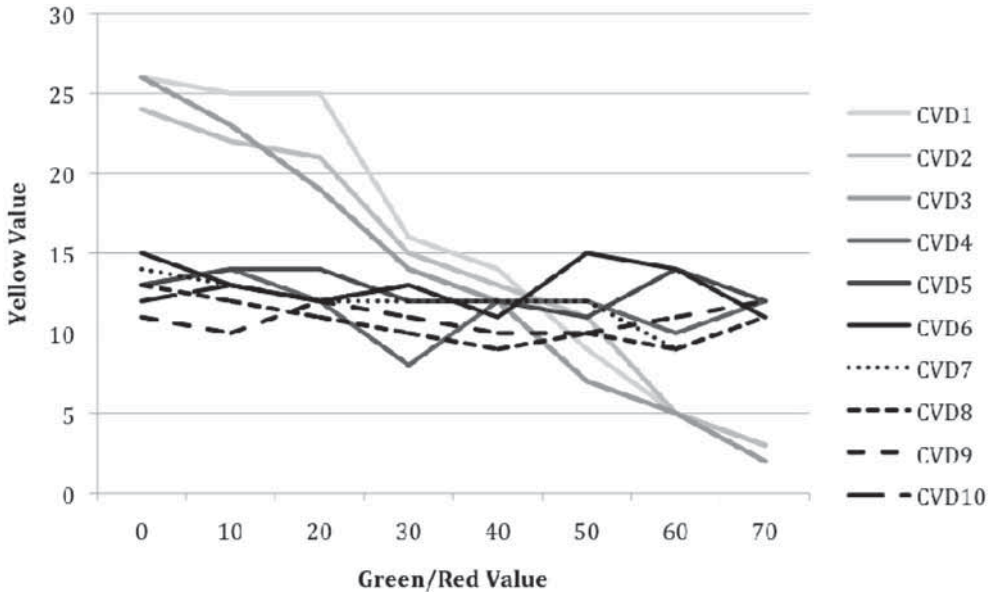

Fig. 2. Matching luminance values for CVDef subjects. For demonstration purposes the results for the right eye only are shown. Three subjects (CVD1, CVD2 and CVD3) have a characteristic protan response starting with high yellow luminance values at 0 (green) which reduced towards the red (70) region of the spectrum. All other responders show similar luminance values across the matching range typical of a deutan response. Subject CVD10, a deuteranomalous trichromat, had a reduced matching range from 30 to 40 green-red ratio only.

incorrect bricks chosen), giving a total error score of 7. The minimum error score was 0, when a subject selected all the correct-coloured bricks. There was no maximum error score as subjects could select as many bricks as they thought matched the original colour within the time limit.

After a tower had been constructed it was disassembled, the bricks shuffled, and a different-coloured brick chosen by the assessor for the next tower. The five towers (red, green, blue, beige and yellow) were constructed randomly under binocular conditions in the light box. The task was repeated under fluorescent (illumination range 230–250 lux) and incandescent illumination (illumination range 50–70 lux) for both the CVNorm and CVDef groups.

Results

The mean age of the CVNorm group was 23.3 ± 3.5 years, and of the CVDef group was 24.2 ± 5.1 years. Standard colour vision tests identified 3 subjects with protanopia, 6 deuteranopes and 1 deuteranomalous trichromat within the CVDef group.

Mean visual acuity for the CVNorm group was -0.18 ± 0.08 logMAR (right eye) and -0.16 ± 0.06 logMAR (left eye). For the CVDef group mean visual acuity was -0.19 ± 0.07 logMAR (right eye) and -0.19 ± 0.10 logMAR (left eye). A two-way ANOVA with eye and group as factors showed no significant difference between left and right eyes ($F_{1,36} = 0.95$, $p = 0.33$) or between groups ($F_{1,36} = 0.36$, $p = 0.55$).

There was no statistically significant difference in mean contrast sensitivity between groups ($F_{1,36} = 1.33$, $p = 0.2$). In the CVNorm group contrast was measured at 1.65 ± 0.10 (right eye) and 1.61 ± 0.10 (left eye). In the CVDef group mean contrast sensitivity was 1.71 ± 0.09 (right eye) and 1.65 ± 0.10 (left eye). A two-way ANOVA with eye and group as factors showed no significance difference between eye ($F_{1,36} = 1.99$, $p = 0.16$) or group.

Nagel anomaloscope

All CVNorm subjects recorded narrow matching luminance ranges that did not exceed 10 units. Fig. 2 shows the colour-matching ranges for colour-deficient participants. The mean colour match was 39.9 ± 3.8 red–green units and 11.4 ± 3.1 yellow units for the right eye with similar results for the left eye (41.5 ± 4.4 red–green units and 13.2 ± 5.3 yellow units). Eight subjects completed the full matching luminance range from 0 (green) to 70 (red) units. The results were similar for right (35.7 ± 16.5 red–green and 10.2 ± 4.0 yellow units) and left eyes (33.6 ± 21.9 red–green and 13.1 ± 5.8 yellow units). Mean matching values for protan subjects were 50.3 ± 20.1 red–green units and 9 ± 6.5 yellow units (right eye) and 39.6 ± 29.8 red–green units and 14.3 ± 12.3 yellow units (left eye). Deuteranope values were different: 30.9 ± 11.9 red–green units and 10.6 ± 3.1 yellow units (right eye) and 31.8 ± 21.8 red–green units and 12.5 ± 1.2 yellow units (left eye).

Ishihara plates

Six of 10 CVNorm subjects recorded no errors whilst completing the Ishihara test. Three subjects had 1 error and 1 subject recorded 4 errors (mean $\pm$ SD: 0.7 ± 1.2 errors). The deuteranomalous subject had 8 errors whilst all dichromats recorded 10 or more errors (mean $\pm$ SD: 14 ± 3 errors). The mean number of errors in the CVDef group was statistically significantly higher (Mann–Whitney: $U = 0.000$, $p < 0.001$) compared with the CVNorm group.

Table 2. Individual error scores for CVNorm subjects using red–green filters under light box illumination. Filters created colour confusion for the colour-normal participants, who recorded many more errors than under normal non-filtered viewing

	Brick colour				
Subject	Blue	Green	Beige	Yellow	Red
CVN1	3	3	9	3	15
CVN2	0	0	7	2	13
CVN3	16	21	17	15	13
CVN4	0	2	9	0	4
CVN5	4	2	5	5	14
CVN6	5	3	10	5	4
CVN7	9	0	1	0	0
CVN8	0	0	1	3	3
CVN9	0	2	6	6	3
CVN10	2	0	5	3	3

D-15 grading test

All CVNorm subjects recorded perfect scores for the D-15 colour matching test with no crossing of the scoring grid. Four CVDef subjects crossed the grid fewer than once (3 deuteranopes and 1 anomalous trichromat). The 3 protanopes and the other 3 deuteranopes crossed the grid at least 8 times (mean $\pm$ SD: 6.7 ± 5.4).

Lego® task

All CVNorm and CVDef subjects were able to complete the task under different illumination conditions and within the imposed time conditions. CVNorm subjects recorded 0 errors for the five types of Lego® brick selected. When red/green filters were worn the CVNorm participants made many errors (Table 2).

The CVDef subjects performed with minimal errors under the three lighting conditions. Seven subjects had 0 errors using light box illumination. The most errors were recorded for 1 deuteranope and 1 protanope. Table 3 shows the individual error scores over the three conditions compared with conventional colour vision tests. Subject CVD3 and CVD8 had maximum error scores over the three conditions. Subject CVD3, a deuteranope, had errors under light box and incandescent illumination. CVD3 identified all but one green brick and repeated this under light box and incandescent conditions. Also under incandescent conditions CVD3 selected all but one beige brick. Subject CVD8, a protanope, had 1 error under fluorescent lighting, incorrectly selecting an additional light green brick when yellow bricks were the task condition. Subject CVD6, a deuteranope, selected all but one beige brick under light box conditions. Subject CVD2, a protanope, incorrectly selected one light green brick instead of yellow and scored a maximum 2 errors under light box conditions.

Using a two-way ANOVA with group and brick as within-subject factors there was no significant difference in performance between the CVNorm and CVDef groups under standard illumination conditions ($F_{1,90} = 2$, $p = 0.16$), under fluorescent conditions ($F_{1,90} = 1$, $p = 0.32$) or under incandescent illumination ($F_{1,90} = 2.88$, $p = 0.09$). Unremarkably the difference between each type of coloured Lego® brick was not significant.

Discussion

All subjects participating in the study had normal vision and contrast sensitivity, and there was no age difference between the CVNorm and CVDef groups. Both the CVNorm and CVDef groups were able to complete the Lego® matching task within the time limit; in fact many completed the task in half the time allocated. The task was therefore considered to be a simple test of colour matching. Under standard room lighting and controlled illumination conditions both groups scored low errors when completing the Lego® matching task.

Looking at individual error scores for the CVDef participants helps understanding of performance in this group. The anomalous trichromat did not score any errors under any lighting conditions. Three of the 9 dichromats (33%) scored at least 1 error under light box conditions. All CVNorm subjects had 0 errors under the same conditions. It may be possible that 1 error is sufficient to identify colour vision deficiency for this group of CVDef subjects that were within higher education programmes. However, this threshold for screening colour vision deficiency is so low that if applied to young children it would be difficult to assess whether the child was (i) colour deficient, (ii) misunderstood the test or (iii) had simply lost concentration. For the remaining dichromats performance was similar to those with normal colour vision under light box conditions. Therefore it appears that using standard Lego® bricks does not detect colour deficiency that is demonstrable using standard colour vision tests.

Red, orange, light green and beige bricks were found to lie within or close to zones of colour confusion for CVDef individuals (Fig. 1*b*, *c*), so it is interesting to speculate on how it was possible for CVDef subjects with almost complete failure on standard colour vision tests to correctly match Lego® bricks.

Table 3. Individual error scores for the Lego® task compared with conventional colour vision test measurements

				Lego® task error scores		
Subject	CV type and severity[a]	Ishihara errors	D-15 crossings	Light box	Fluorescent conditions	Incandescent conditions
CVD1	Protanopia	16	11	0	0	0
CVD2	Protanopia	15	11	2	0	0
CVD3	Protanopia	16	8	0	1	2
CVD4	Deuteranopia	12	0	0	0	0
CVD5	Deuteranopia	10	1	0	0	0
CVD6	Deuteranopia	16	13	1	0	0
CVD7	Deuteranopia	16	12	0	0	0
CVD8	Deuteranopia	15	0	1	0	2
CVD9	Deuteranopia	16	9	0	0	0
CVD10	Deuteranomalous	8	1	0	0	0

[a]CV type and severity were identified using the Nagel anomoloscope.

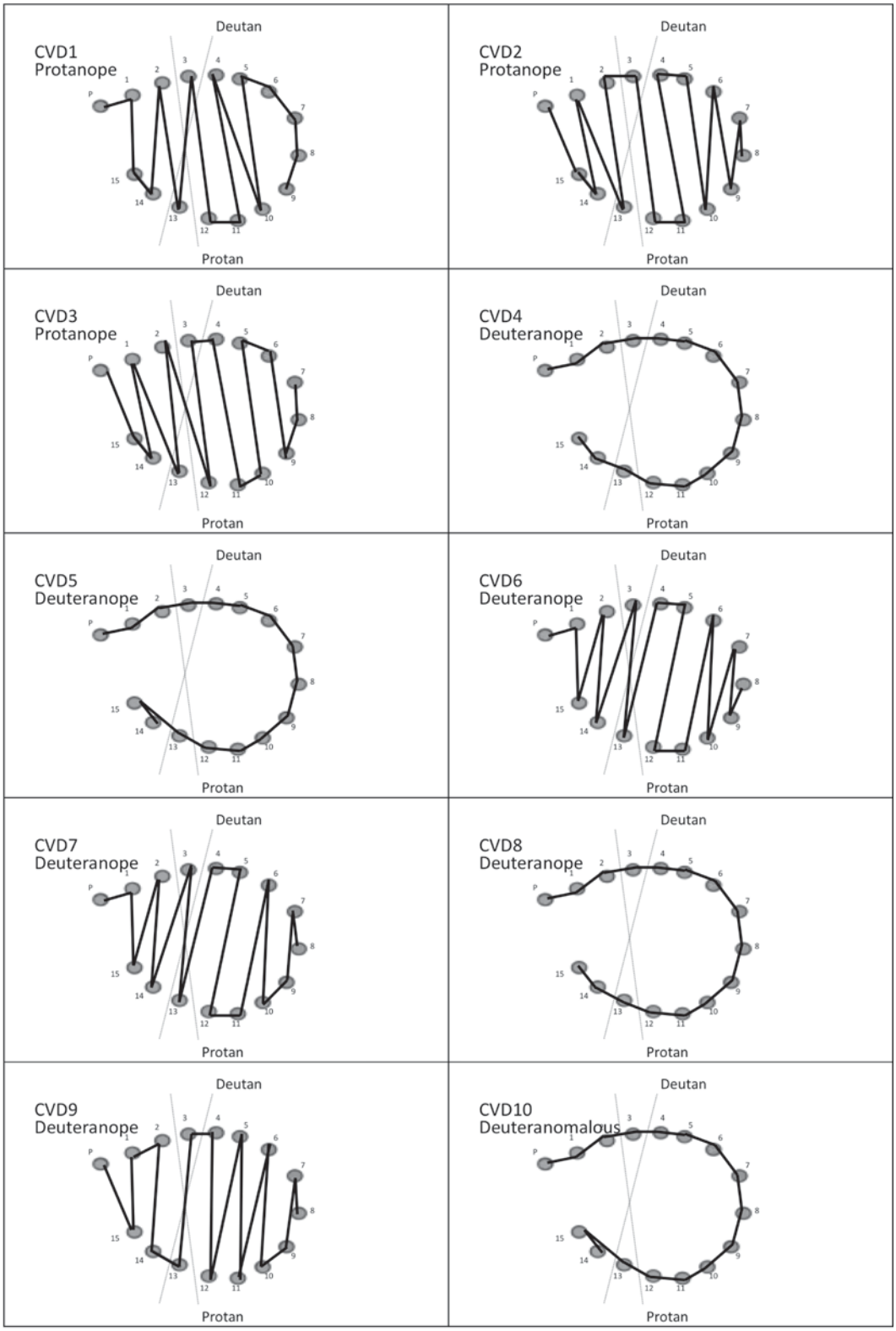

Fig. 3. D-15 graphical results for the CVDef subjects. The axis of colour confusion is shown for deutan and protan only. The subject's colour vision defect (as identified by the anomaloscope) is also displayed for each result.

It is possible environmental factors may assist in determining the correct-coloured brick. All subjects were young adults and it is possible that through learning the subjects were able to detect luminance differences in different-coloured bricks without knowing the specific colour of the brick. All subjects were male and some informed the examiner that they had previously played with Lego® during childhood, and hence may have developed strategies to assist in colour matching.

Table 4. Luminance values for Lego® bricks under standard illuminant C conditions. Distinguishing between red and black bricks was predicted to cause colour confusion for protan subjects, yet red had a higher luminance value that may assist in colour matching

Colour	Black	Blue	Green	Red	Orange	Light green	Beige	White	Yellow
Luminance (cd/m^2)	4.86	10.9	16.0	17.5	30.4	39.2	61.2	63.3	73.3

Standard Lego® bricks were chosen for the pilot study to replicate equipment that would be available in clinic waiting areas. These bricks are commercially successful and appeal to young children by virtue of their different colours. Despite some bricks being within zones of colour confusion the luminance of the bricks may be associated with good colour discrimination for colour-defective subjects. The luminance value of each brick was measured using the PR-650 Spectrometer to establish whether brightness assisted the ability of the CVDef groups to correctly match the bricks. Table 4 shows the luminance values for each brick.

Luminance values varied throughout the range of Lego® bricks and probably assisted the CVDef subjects with the matching task. Under incandescent conditions the most likely mistake by protanopes was confusion between red and black, the small difference of 13 cd/m^2 suggesting possible confusion. It is possible that differences in colour of standard Lego® bricks are discriminated due to the luminance values.

It was possible to record some errors within the CVDef group, the largest error being between yellow and light green under light box conditions. However, many CVDef subjects subjectively reported after they had completed the task that some coloured bricks were more confusable than others. Four deuteranopes reported difficulty matching yellow, beige and light green, whilst distinguishing between yellow and orange was also highlighted as a potential problem. Subject CVD3, a protanope, reported confusion with distinguishing yellow from light green and red from brown bricks. Only when the incorrect brick was placed alongside the correct brick was the incorrect brick rejected. This was allowed in the methodology as long as the tower was completed within the time limits. It would be interesting to repeat the experiment in a way in which individuals could not reject a brick once selected; this may increase error rates.

It appeared the test was not difficult, as all subjects completed the task within the given time limits, and it is likely very young children would be able to co-operate with this colour-matching task. It is possible young children who have congenital colour deficiency yet are unaware of their condition may respond differently to this group of young adults. All CVDef subjects were aware of their colour deficiency and subjectively reported no complications recognising coloured objects during everyday vision. It appears the CVDef subjects have adapted to their colour deficiency, and presumably learned relative luminance comparisons from their experience. It would be interesting to carry out a longitudinal study investigating colour vision in young children using Lego® bricks to assess at what age children with defective colour vision begin to learn how to use this adaptation.

Returning to the aim of the study, it was found that using Lego® bricks to assess colour vision is simple and practical, but it appears to produce very low error rates with adult subjects. Some individuals identified by the anomaloscope and Ishihara plates as having severe colour confusion recorded perfect colour matching with Lego® bricks. If this result were repeated with young children, the test would not be suitable. This form of colour vision testing cannot be recommended as a single colour vision test at this time. Currently established tests such as Colour Vision Testing Made Easy (CVTME; TL Wagner, Home Vision Care, Anaheim, CA, USA) or plates 1 (introduction), 6, 7 (transformation), 10, 14 (vanishing) and 24 (classification) of the 38-plate Ishihara test are the colour vision tests clinicians are most likely to use to assess colour perception in young children. The rationale for using these plates is that they all contain numerals between 1 and 5 and children beginning school are familiar with those numbers.[9] These tests require colour identification, which is different from the colour matching used in the Lego® brick task. An alternative colour arrangement test known as the Mollon-Reffin minimalist (M-R M) colour vision test is highly suitable for young children yet not widely publicised.[10] The M-R M uses three series of coloured caps coinciding with protan, deutan and tritan confusion axes and is successfully completed by children as young as 3 years old. A combination of these conventional tests may be considered useful to measure colour vision in young children. However, colour vision should be tested again with conventional colour diagnostic tests when it is possible to obtain repeatable measurements.

We thank Margaret Freemantle, Orthoptist at Hull Royal Infirmary, who originally developed the idea of using toys to assess colour perception with young children.

References

1. Holmes W. Colour vision testing: what can be achieved in everyday practice? *Optom Practice* 2011; **12:** 167–178.
2. Cumberland P, Rahi JS, Peckham CS. Impact of congenital colour deficiency on education and unintentional injuries: findings from the 1958 British birth cohort. *Br Med J* 2004; **329:** 1074–1075.
3. Kinnear P, Sahraie A. New Farnsworth–Munsell 100 hue test norms of normal observers for each year of age 5–22 and for age decades 30–70. *Br J Ophthalmol* 2002; **86:** 1408–1411.
4. Formankiewicz M. Consequences and treatment of colour vision deficiencies. *Optom Today* 2009; **49:** 35–42.
5. Suero MI, Perez AL, Diaz F, Montanero M, Pardo P, Gil J, *et al*. Does Daltanism influence children's learning? *Learn Indiv Diff* 2005; **15:** 89–98.
6. Wright WD. A re-determination of the trichromatic coefficients of the spectral colours. *Trans Opt Soc Lond* 1938; **30:** 141–164.
7. Margrain T, Birch J, Owen C. Colour vision requirements of firefighters. *Occup Med (Lond)* 1996; **46:** 114–124.
8. Pelli, D, Robson J, Wilkins A. The design of a new letter chart for measuring contrast sensitivity. *Clin Vis Sci* 1988; **2:** 187–199.
9. Birch J. *Diagnosis of Defective Colour Vision*. Oxford: Butterworth-Heinemann, 2001.
10. Shute RH. Westall CH. Use of Mollon–Reffin minimalist color vision test with young children. *J AAPOS* 2000; **4:** 366–372.