TITLE PAGE

Title: Syringe labels seen through the eyes of the colour-deficient clinician.

Running title: Syringe labels and deficient colour vision.

Authors:

Peter B. M. Thomas PhD FRCOphth, Department of Paediatric Ophthalmology and Strabismus, Moorfields Eye Hospital, 162 City Road, London EC1V 2PD, UK; NIHR Biomedical Research Centre at Moorfields Eye Hospital, London, UK.

John D. Mollon DSc, Department of Psychology, University of Cambridge, Downing Street, Cambridge CB2 3EB, UK

Summary

Colour codes are commonly used in the clinical environment, but there is little advice on how to design them to be appropriate for the colour-deficient clinician. Guidelines, backed by the Royal Colleges of Anaesthetists and Emergency Medicine (among other organisations), are available for the colour coding of syringe labels in critical care areas in the UK and Ireland. Similar guidelines exist in the United States, and an International Standard has also been published. The guidance is well thought through, and, for the clinician with normal colour vision, aids in the quick and easy distinction between different classes of medication. However, we find that several of the colours used are confusable to the colour-deficient clinician. We present reconstructions that allow someone with normal colour vision to appreciate how a colour-deficient observer sees the recommended syringe labels. We also present a colorimetric analysis of syringe labels (gathered using spectroradiometry) and of the colours recommended in the various guidelines. This analysis confirms the existence of potential confusions and also identifies an ambiguity in the published specification for neuromuscular blockers. Since there are no minimum colour vision requirements to entering medical practice, it is likely that there are around 400 NHS anaesthetic consultants with deficient colour vision, and many more trainees and allied health professionals. We hope that awareness of the potential for confusions in clinical colour codes might benefit future colour code design, and benefit patient safety.

Correspondence:

Colour serves many purposes in the hospital environment. Clinically, a common use is to distinguish between variants of a piece of equipment, for example blood tubes or sizes of cannula. There is little guidance on which colours should be used in constructing a safe and helpful colour code, and the choice is generally left to manufacturers. A rare exception to this is the labelling of syringes in critical care areas, for which clear and well thought out guidance is provided[1]. The guidance is backed by the Royal College of Anaesthetists, the Association of Anaesthetists of Great Britain and Ireland, the Royal College of Emergency Medicine, the Intensive Care Society, and the Faculty of Intensive Care Medicine. Similar guidelines are issued in the United States[2] and there is also an ISO standard[3]. For the individual with normal colour vision, there is little scope for confusion with such labels, as they use a mixture of colour, hatching, and reversal of font and background colour. There is evidence that syringe labelling systems can enhance the safe use of medication[4].

Colour deficiency (the term now preferred to "colour blindness") is common, and can be acquired (for example in glaucoma), or congenital. When congenital, it is almost always of the type characterised as "red-green colour blindness", an X-linked condition. This affects around 8% of the male population[5] (and a far smaller proportion of females), and can be mild or severe. In the more severe form, the observer is dichromatic, relying on two rather than three cone classes, owing to loss of middle- or long-wavelength-sensitive cones (conditions termed respectively 'deuteranopia' and 'protanopia'). Around 2.5% of the male population are dichromatic[5]. Using mathematical transforms, it is possible to modify the appearance of a photograph so that the normal observer can see the image as it would appear to a dichromat[6].

In the UK, as in most countries, no restrictions are placed on entry of the colour-deficient candidate into any branch of medicine. In India, several medical students were recently rejected from medical school, but the decision was overturned on appeal to the Indian Supreme Court[7]. Certain clinical distinctions are more difficult for the colour-deficient doctor[8], but there has been no formal or useful guidance on how clinical colour codes should be constructed to accommodate the colour deficient. In 2015, there were 7,422 NHS anaesthetic consultants, 68%[9] (5,047) of whom were male. Unless self-selection occurs for particular specialities, there are likely around 288 anaesthetic consultants with milder forms of red-green deficiency, and 126 with the more severe form (dichromacy). The prevalence among other staff groups in the anaesthetic and critical care environments is also likely to reflect that of the general population.

One aspect of the accepted syringe labelling code is colour[1], and specific Pantone® colours are recommended for each class of drugs. All labels include the drug name and a space in which to write the concentration. Antagonists are marked with stripes, while suxamethonium and adrenaline have the font and background colour reversed to stand out. Figure 1 shows labels for the major drug classes, and reconstructions of how these labels appear to the two common types of dichromat. Using a PhotoResearch 650 spectroradiometer with macro lens, we measured the chromaticities of a representative set of syringe labels and of the Pantone® colours suggested in the guidance[1] (uncoated Pantone® by Letraset™ swatch). In Figure 2 the colours suggested in the most current guidelines[1,3] are plotted in the CIE (1931) chromaticity diagram, a standard 2-dimensional space that allows all colours to be represented and also allows a direct prediction of which combinations of colours will be indistinguishable to the three classes of dichromat – i.e. combinations that fall on "dichromatic confusion lines".

The chromaticities are well separated in the CIE (1931) diagram, a result consistent with the impression from visual inspection that the colours are appropriate for the individual with normal

colour vision. For the colour-deficient observer, however, there are shortcomings. For dichromats of the protan type, the chromaticities for vasopressors and opioids, as well as those for anti-emetics and neuromuscular blockers, fall on confusion lines. For dichromats of the deutan type, anti-emetics and anticholinergics fall on a confusion line. For dichromats of the tritan type, vasopressors and local anaesthetics fall on a confusion line. However, if we use not the printed labels but rather the colours shown in the UK and Ireland guidance (Figure 1), then one interesting difference emerges: neuromuscular blockers are confusable with local anaesthetics, and not with anti-emetics.

We find that this discrepancy arises because of ambiguity in the guidance for the shade of red that should be used for neuromuscular blockers. The text of the UK and Ireland guidance specifies "Pantone® 805 (fluorescent or warm red)", but "warm red" is a distinct colour from Pantone® 805, while "fluorescent red" doesn't exist in the Pantone® system (confirmed by discussion with Pantone LLC). The colour used on the printed labels available to us corresponds to "sup warm red" (on our Pantone® swatch) which falls on a confusion line with anti-emetics, while Pantone® 805U falls on a confusion line with local anaesthetics. Thus, even by following the guidelines, different manufacturers could produce label sets that contain different confusions for the dichromatic doctor. By comparison, in the ISO system all suggested colour choices for neuromuscular blockers fall on a confusion line with anti-emetics, and never with local anaesthetics.

Where a colour code is widespread, it is likely to replace other means of visual identification (especially text) both in communication between team members (e.g. "insert a grey cannula"), and for the individual when searching for a particular item. Colour coding is particularly useful when speed is of the essence, as it often is in the critical care and anaesthetic environments. The accepted guidance[1] for syringe labels will encourage reliance on the suggested colour code. Figures 1 and 2 show that certain colours used in this code will be confusable for around 400 consultant anaesthetists (and many more trainees and allied health professionals) in the UK. Some of these clinical staff will be alert to their colour deficiency, but many may be completely unaware of it[10]. This raises the possibility of drug errors leading to patient harm either by accidental administration of an inappropriate agent, or by failure to administer the correct agent.

The recommended labelling system is excellent for clinicians with normal colour vision, and its adoption has undoubtedly been a huge improvement on the pre-existing situation. But should it be modified so as not to disadvantage colour-deficient clinicians? Should, for example, a symbolic form cue (such as a wavy horizontal line) be added to the labels for neuromuscular blockers? There is an obvious danger of prompting a paradoxical increase in errors by changing a code that is already widely established. Moreover, there is no empirical evidence that errors are in fact more frequent among colour-deficient staff, whether experienced or inexperienced. We therefore confine ourselves to recording which pairs of labels are confusable by colour-deficient observers – and to drawing attention to the ambiguity in the published specification of the colour code for neuromuscular blockers.

References:

1. Woodcock, T. *Syringe labelling in critical care areas review 2014*. (2014).
2. Standard Specification for User Applied Drug Labels in Anesthesiology 1. doi:10.1520/D4774-11R17
3. Anaesthetic and respiratory equipment — User-applied labels for syringes containing drugs used during anaesthesia — Colours, design and performance. *Ref. number ISO* **26825,** (2008).

4. Webster, C. S. *et al.* Clinical assessment of a new anaesthetic drug administration system: a prospective, controlled, longitudinal incident monitoring study. *Anaesthesia* **65,** 490–9 (2010).

5. Pokorny, J., Smith, V. C., Verriest, G. & Pinckers, A. J. *Congenital and Acquired Color Vision Defects*. (Grune and Stratton, 1979).

6. Brettel, H., Viénot, F. & Mollon, J. D. Computerized simulation of color appearance for dichromats. *J. Opt. Soc. Am. A. Opt. Image Sci. Vis.* **14,** 2647–55 (1997).

7. SC directs admission of two colour-blind students in MBBS. *The Hindu* (2017).

8. Dhingra, R., Rohatgi, J. & Dhaliwal, U. Preparing medical students with congenital colour vision deficiency for safe practice. *Natl. Med. J. India* 30–35 (2017).

9. Royal College of Anaesthetists. *Medical Workforce Census Report 2015. The Royal College of Anaesthetists, UK.* (2016).

10. Cole, B. L. Assessment of inherited colour vision defects in clinical practice. *Clin. Exp. Optom.* **90,** 157–175 (2007).

11. Asada, K. Chromatic Vision Simulator. Available at: http://asada.tukusi.ne.jp/cvsimulator/e/index.html.

Declaration of interests: none.

Funding: nil

Acknowledgements:

The research was supported by the National Institute for Health Research (NIHR) Biomedical Research Centre based at Moorfields Eye Hospital NHS Foundation Trust and UCL Institute of Ophthalmology. The views expressed are those of the author(s) and not necessarily those of the NHS, the NIHR or the Department of Health.

Authorship:

PT and JM – contributed equally to all aspects of this work.

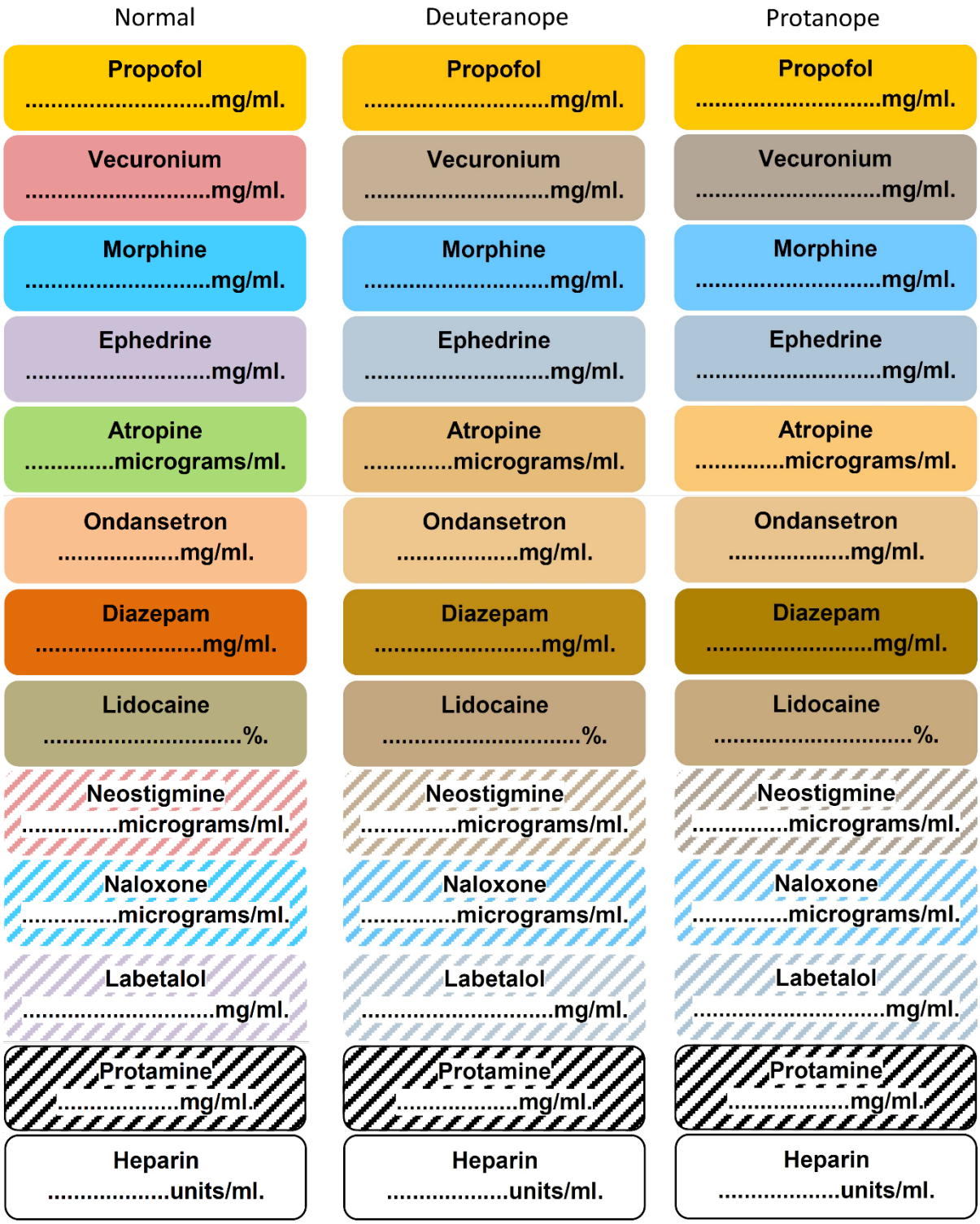

Figure 1. The left column shows the colour code recommended by, among others, the Royal College of Anaesthetists [1]*. The centre column shows how these appear to deuteranopes (the more common group of dichromats), and the right column is the equivalent for protanopes. The pink label of vecuronium (used for all neuromuscular blocking agents) loses its colour when transformed for the dichromat, coming to closely resemble the grey of the lidocaine label (used for all local anaesthetics). Similarly, the green and pink hues of anticholinergic agents (atropine) and anti-emetics (ondansetron) respectively lose their colour to become similar intermediate beiges. Transformations were created using software*[11] *based on established methodology*[6]*.*

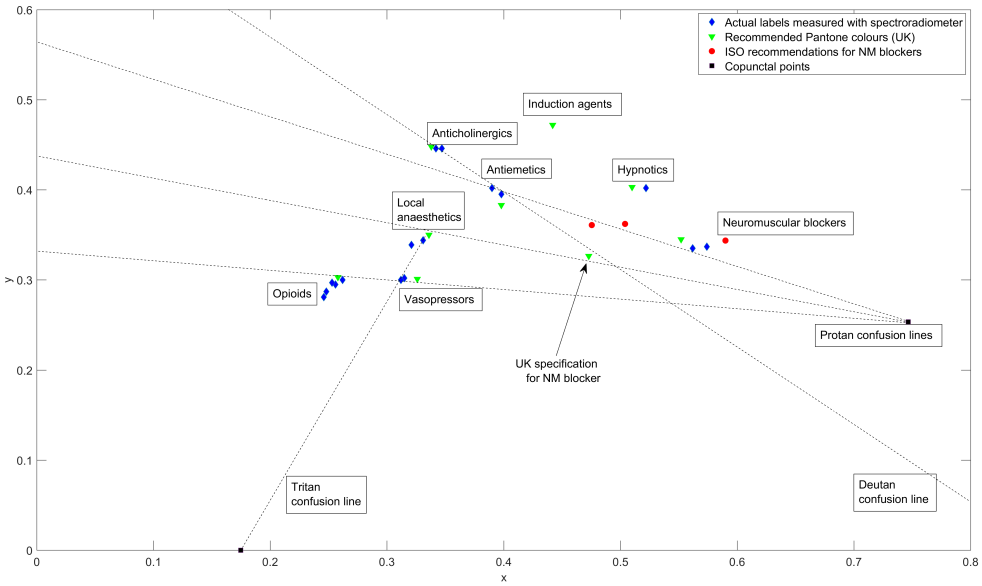

Figure 2. CIE 1931 colour space showing chromaticities of labels recorded by spectroradiometry (diamonds), colours recommended by the UK guidance (triangles), and colours recommended by ISO standard. Any pair of chromaticities lying on a line that passes through a co-punctal point are potentially confusable. The deutan co-punctal point is out of the bounds of this plot at x=1.4, y=-0.4. Confusion lines are illustrated for chromaticity pairs described in the text.