Occupational colour vision needs with emphasis on aviation

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ABSTRACT

The novel experiments and tests developed for this study yield new data that describe how combinations of luminance contrast and Red / Green (RG) and Yellow / Blue (YB) colour signals affect task completion times (TCT) and the overall accuracy the operator can achieve.

With appropriate design and choice of colours, it is possible for deutan applicants with thresholds < 4 standard normal CAD units to perform as well as normal trichromats when suprathreshold colours with RG and YB components are employed in visual displays. As many as 22% of deuteranomalous subjects can be included in this category. In spite of their congenital colour deficiency, such applicants can operate safely in the Air Traffic Control (ATC) environment as well as in many other occupations that involve the use of large-field, visual displays.

1. INTRODUCTION

Colour is arguably a very effective and compelling but also attractive and efficient method to enhance performance on visual displays. The use of colour signals can benefit visual performance in a number of ways:

- Colour signals enhance the 'effective' contrast of objects defined by luminance contrast (Barbur & Forsyth 1988). When luminance contrast is low, the addition of colour signals, particularly to targets defined by luminance increments, results in improved visual performance and shorter task completion times.

- Pop-out and parallel processing of colour signals (Treisman & Gelade, 1980) is particularly useful when the working task involves the use of crowded scenes in large visual displays. Objects of reasonable size that in addition to luminance contrast are also coloured can often be detected and localised in crowded scenes without the need for any eye-movements. In such cases, the visual search is reduced to a single saccade which directs the subject's point of regard onto the target.

- Signaling and enhancing information by means of colour coding can be a very effective way of improving visual performance. The display of weather patterns in an airplane cockpit uses specific colours to differentiate between levels of precipitation. The detection and correct naming of reds and whites from a large distance in the Precision Approach Path Indicator (PAPI) lights when landing an airplane is a good example of a safety critical task.

- Segmentation of complex scenes into areas of interest by means of colour can also be of great benefit in visually demanding tasks. The human visual system organizes complex scenes into meaningful objects and / or spatially distinct regions. This is often described as 'segmentation' (Pinker 1984). Visual segmentation can focus attention and enhance performance by making the visual task less demanding and less tiresome. For example, a controller can spatially separate the aircraft situations area, or the number of aircraft of immediate responsibility from the menu areas in a radar display.

Technology advancements in the design and production of visual displays have increased greatly the use of colour to provide many of the benefits described above. The obvious requirement is that the operator must be able to make use of colour signals and this often assumes the need for normal trichromatic colour vision. Several studies carried out in selected working environments have, however, demonstrated that although colour vision is needed to enhance visual performance and to carry out visual tasks that are often safety-critical, subjects below specified levels of colour vision loss can cope with the safety-critical, suprathreshold, colour-related tasks with the same accuracy as normal trichromats (Barbur and Rodriguez-Carmona, 2012).

The aim of this study was to investigate the use of colour signals in occupations with emphasis on Air Traffic Control (ATC) applications.

2. METHOD

Normal trichromats and many subjects with congenital colour deficiency took part in this study. Each subject's colour vision was investigated with a number of conventional colour vision tests and the class of colour vision and severity of loss were determined using the Colour Assessment and Diagnosis (CAD) test (Barbur and Connolly, 2011). A new, CRATO test was also designed specifically for this study. The Colour Requirements for Air Traffic Operators test measures the mean speed of response (labelled as 'Task Completion Time' (TCT)) and the percentage correct scores (PCS) for visual tasks that involve large visual fields and for stimuli of equivalent size and contrast to the data blocks employed in ATC displays. Although the objects employed are somewhat abstract since they consist of similar targets and distractors, the use of such stimuli makes it possible to evaluate how target contrast and colour affect visual performance. Stimuli were presented over a square region subtending ~ 20° of visual angle on a high resolution, 'spectraview', NEC monitor (PA301W, Tokyo, Japan). The background field was set at a luminance of 32 cd/m^2 and had a chromaticity of $x_b = 0.305$, $y_b = 0.323$ in CIE-x,y 1931 colour space. The coloured stimuli in all experiments were defined as chromatic displacements from background chromaticity (x_b, y_b) in specific colour directions. The programs needed for the study were developed by City Occupational Ltd (London, UK). The display calibration programs were the same as those employed in the CAD system (Barbur and Connolly 2011).
The CRATO test was used with a limited number of subjects: 33 normal trichromats and 37 subjects with deutan- and protan-like colour deficiencies. The age of the subjects ranged from 17 to 65 years (mean 37 years, median 34 years). Subjects had a visual acuity of 6/9 or better.

2.2 Principal Experiment

The study involved many visual serach experiments with targets defined only by spatial cues, spatial cues and colour or only by colour. In each experiment the subject had to search the visual scene to find the test target and to indicate this as quickly as possible by pressing a button. This recorded the TCT. The subject was then required to press one of four buttons to indicate either the orientation of

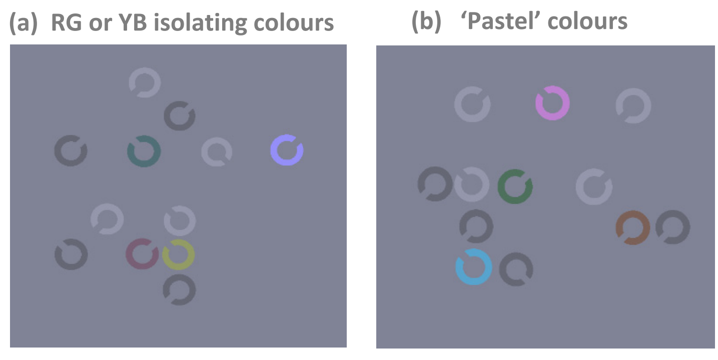

Fig. 1 (a, b). Examples of RG and YB isolating colours (a) and 'pastel' colours (b). The latter are defined by a combination of RG and YB colour signals. Congenital colour deficients with thresholds < 4 CAD units perform as well as normal trichromats when saturated 'pastel' colours are employed, but have longer TCTs for RG isolating colours (a).

a gap in a Landolt ring stimulus or its colour in order to measure the subject's PCS. The most important experiment involved the use of colours that isolate either RG or YB chromatic mechanims (Fig. 1A) or 'pastel' colours defined by combined RG and YB signals (Fig. 1B).

3. RESULTS AND DISCUSSION

The results confirm well established findings which show the importance of luminance contrast and the use of colour signals in visual search. In addition, the following new experimental findings have emerged from the study:

- Targets with higher luminance contrast can be detected quicker and easier than those of lower contrast, but the addition of colour signals to such targets can greatly reduce TCTs and also improve task performance accuracy.

- TCTs decrease gradually with increasing colour signal strength with little additional benefit above 10 to 12 standard normal (SN) CAD threshold units (Rodriguez-Carmona et al., 2012). This is also the case when spatial cues are involved and the task can be carried out in the absence of colour signals.

- Both RG and YB colour signals yield significant advantages by shortening visual search times (often as much as four fold), even when colour is used redundantly and the task can be completed without the use of colour signals.

- When task specific information is displayed over large visual fields, YB colour signals have some advantage over RG, largely because YB chromatic sensitivity falls off less rapidly with increasing distance on the retina between the point of regard and the target location. Although RG signals, particularly when small targets are involved, have advantages over YB signals in central vision, the opposite seems to be the case when the working visual field is large.

- Colour signals are more effective when added to targets defined by increments in luminance (i.e., when viewing bright as opposed to dark objects presented against a uniform background). This observation applies to both RG and YB stimuli.

- In general subjects with even mild congenital RG colour deficiency perform less well when the task involves the use of colours of low chromatic saturation which they confuse, i.e., colours that differ mostly in RG content. The same, mildly deficient subjects perform as well as normal trichromats in the same task when YB colour signals are employed.

- Subjects with mild congenital colour deficiency (e.g., those with thresholds less than ~ 4 SN CAD units) can perform colour related tasks when several coloured targets are involved, but only when larger chromatic saturations are employed (i.e., > 10 SN CAD units). The addition of YB colour difference signals to targets defined by luminance and RG colour contrast ensures that mild congenital colour deficients perform visual search tasks with virtually the same speed and accuracy as normal trichromats.

- Visual performance in dichromats and also in subjects with severe loss of RG colour vision is significantly worse when compared to normal trichromats except for colours that rely heavily on YB colour differences.

4. CONCLUSIONS

The key conclusions listed below are based on measurements of visual performance in large field, visual displays which quantify the advantages of adding RG and / or YB colour signals to objects defined by luminance contrast.

- If the visual task requires detection and naming of colours for small signal lights (e.g., red, green, yellow, blue and white, etc.), or the discrimination of the smallest possible colour differences in order to judge uniformity of colour reproduction in manufactured goods, or the need to adhere to the commonest appreciation of perceived colour appearance and colour names and / or the ability to use efficiently faint, desaturated colours to segment objects into groups on visual displays, a pass requires normal trichromatic colour vision.

- If large chromatic saturations are employed, subjects with mild RG colour deficiency (e.g., those with RG thresholds ≤ 4 CAD units) will be able to make use of the reduced RG colour signal to carry out the colour-related task, but these subjects will be a little slower than normal trichromats when the tasks require visual search in large displays.
- When suprathreshold YB colour difference signals are also added to objects defined by luminance and large RG colour contrast, congenital deficients with RG thresholds ≤ 4 CAD units can perform multi-colour visual search tasks with the same accuracy and speed as normal trichromats.

ACKNOWLEDGEMENTS

We wish to acknowledge the UK Civil Aviation Authority and the COLT foundation for supporting this work and City Occupational Ltd for programming the CRATO tests.

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