An example of applied colour vision research: the conspicuity of airplane colour

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Abstract

This paper describes the application of the combined knowledge on colorimetry, colour imaging (visualization) and colour perception in an aviation related research project. It involves the optimisation of the conspicuity of the colour scheme of an airplane, with the purpose of minimizing the changes of a mid-air collision. Subjects determined the conspicuity (here defined as object detection in the visual periphery) of different airplane colours at a simulated distance of 1 km and for different simulated atmospheric visibilities. Results indicate that the conspicuity depends on the lightness difference between the airplane and its background, but not on the difference in hue or saturation.

Figure 1. Photographs of the Pilatus PC-7. Length and wingspan are about 10 m. The current colour scheme is mainly yellow, red, white and black. When observed from a distance of 1 km, this aircraft subtends a visual angle of 1 degree (about the size of a thumbnail at arm's length).The black "nose" just in front of the cockpit prevents the pilot from being blinded by reflected sunlight.

Introduction

Figure 1 shows two views of a Pilatus PC-7 aircraft that is used by the Royal Netherlands Air Force for initial pilot training. Although the colour scheme of the aircraft (mainly yellow, red, white and black) would suggest the aircraft to be a conspicuous appearance, there have been a number of reported near-collisions in the air in which the PC-7 was involved. The question therefore was whether or not the conspicuity of the current colour scheme (as shown in Fig. 1) could be improved, so as to minimize the change of a mid-air collision. For avoiding a collision in the air, pilots must 1) visually detect other airplanes; 2) identify these airplanes and determine their course; 3) change course if necessary. This paper is concerned with the first step only, i.e. the detection of an object in the visual periphery. The periphery differs from the central part of our visual field in a number of ways. Probably the most relevant differences for this research are the strongly reduced visual acuity [1] (the ability to distinguish small details), and the reduced colour discrimination [2,3] in the periphery. Unfortunately, it is often believed that we are virtually colour blind in the visual periphery. However, when the visual stimuli are made large enough, our colour discrimination abilities in the periphery are quite well preserved.

Definition of conspicuity

Conspicuity must not be confounded with *visibility*. Visibility usually pertains to the ability to see an object with the central area of our visual field (the fovea). The term conspicuity however relates to the degree with which an object stands out from its background. The more conspicuous the colour of an object, the sooner an observer will spot it when asked to search for the object in a visual scene. We have previously developed and patented a method and an instrument for measuring the conspicuity of objects. The principle behind it is simple. An observer determines the maximum angle that can be looked away from the object without "losing" the object in the visual periphery. That is, the object must still be visible without making an eye-movement to the object. The maximum angle thus obtained has been shown to correlate well with search time [4]. We can also distinguish between conspicuity related to the *detection* or to the *identification* of the object. For the latter, smaller conspicuity angles will be measured. In this research we used the detection threshold for measuring the conspicuity of (simulated) differently coloured aircrafts, in a static situation. The latter is considered to be most critical (two airplanes set at a collision course have no relative motion). It can be argued that the conspicuity of objects moving in the visual periphery will be higher than that of static objects.

Measurement of visual conspicuity

Subjects looked at images displayed on a calibrated, high-resolution colour CRT (Philips Brilliance 2110). The monitor was positioned at a central window in a white projection screen. With two slide-projectors a neutral light level of about 35 cd/m^2 was generated on the projection screen. At a viewing distance of 3.5 m from the monitor and projection screen, subjects were standing behind a large tripod. A chin- and headrest was mounted on top of the tripod to facilitate a stable viewing position. Using a turning wheel, the subjects were able to rotate the upper part of the tripod (around the vertical axis, in the horizontal plane), thereby changing the angle between their line of sight and the aircraft displayed at the center of the CRT image. To make sure that the observers kept their eyes “away” from the target (the aircraft) they were instructed to keep looking at a laser spot on the projection screen. This laser spot came from a small HeNe laser (red light, 632 nm) that was also mounted on the upper part of the tripod that rotated. Starting with a large angle (about 80 degrees) the subjects gently decreased the angle between the fixation point (the laser spot) and the aircraft image until they could detect the aircraft in the periphery. This threshold angle was read from a goniometric device attached to the tripod. In cases where the subjects indicated that it was difficult to determine the threshold angle, they were instructed to vary the angle between values where they were certain about the presence or absence of the airplane in the periphery. This always resulted in an acceptable threshold angle.

Image preparation

The images presented to the subjects were scaled down versions of digitised photographs of the PC-7 aircraft in the air. From the 3.5 m observer distance, the aircraft as seen in the image subtended a visual angle of 1 degree, as if it were at a distance of 1 km[1]. The colour of the aircraft was either left unchanged (see Fig.1 for colour scheme) or completely changed into black, white, grey, red, yellow, green or blue. Two experiments were carried out. In Experiment 1 (three subjects) the aircraft colour was original, black or white, at five different settings for simulated meteorological (atmosphere) conditions. The effects of contrast reduction and colour de-saturation due to atmospheric attenuation of light were simulated for five levels of the meteorological visibility. To do this, two colour processing steps were necessary. First, for each colour in the image a smooth spectral reflectance function was estimated [5] under the assumption of a homogeneous daylight (D_{65}) illumination. Second, a wavelength-dependent model for light transmission through the atmosphere was applied [6] to each colour. Assuming the colours to be at a 1 km distance, the effects of atmospheric attenuation can be considerable (depending on the setting of the atmospheric visibility). Fig. 2 shows some examples.

Figure 2.Examples of the images used in the experiments. Top row, left to right: original colour scheme (mainly yellow), completely white and completely black. Top to bottom: simulated effect of decreasing atmospheric visibility.

In Experiment 2 (four subjects), the aircraft colour was red, green, yellow, blue or grey (at the same luminance as the colours) for the maximum meteorological visibility. The neutral background of the aircraft could be light or dark, to create both luminance increments and decrements for the target.

Results

Figure 3 shows an example of the results obtained in Experiment 1 with the airplane shown against a dark blue sky. The data points are the averages of three observers; error bars represent the standard deviation. For this particular condition, the conspicuity values of the white colour scheme are higher than those for the current yellow colour scheme and the black colour scheme, for all values of the simulated atmospheric visibility. This is due to the dark blue background, which causes a large luminance contrast with the white airplane. Against a

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[1] The distance of 1 km was selected as fixed distance throughout the research. Two PC-7 aircrafts approaching each other at maximum speed would need 5.5 seconds to bridge 1 km.

light background the opposite effect would become visible. Note that the effect of a reduced conspicuity with diminishing atmospheric visibility is correctly registered by our method.

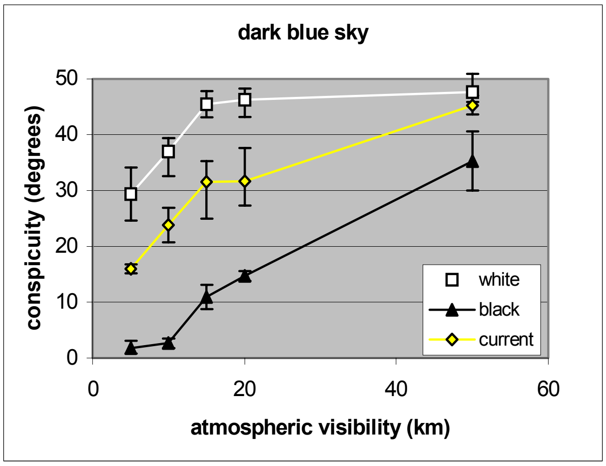

Figure 3. Data example of three airplane colour schemes shown against a dark blue sky. The original images, without addition of the atmospheric effect, were assigned a visibility of 50 km.

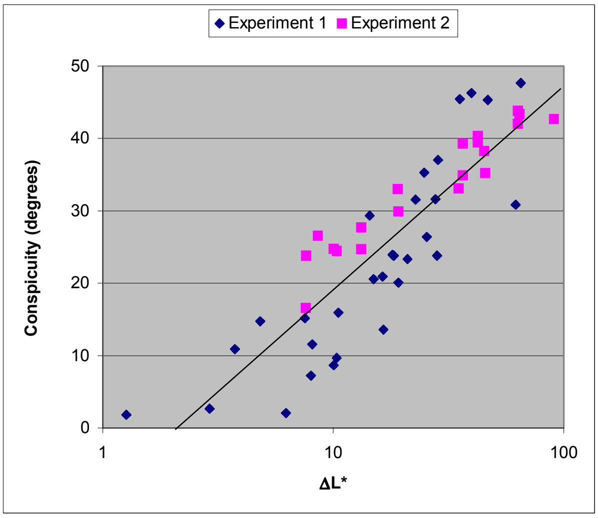

Figure 4. Pooled data from experiments 1 and 2, showing the measured conspicuity versus the difference in lightness between the airplane and the background. Note the logarithmic scale.

Fig. 4 summarizes the results of the two experiments. Since conspicuity was somehow expected to relate to the colour difference between an object and its background, the measured threshold angles for peripheral detection were initially plotted against the colour difference between the airplane and its background. Of the many colour difference measures that exist, we selected one that consists of three contributions closely related to visual descriptors (difference in hue, saturation and lightness). This colour difference, ΔE*, is defined as [7]:

$$\Delta E^* = \sqrt{(\Delta L^*)^2 + (\Delta C^*)^2 + (\Delta H^*)^2} \qquad (1)$$

where ΔL*, ΔC* and ΔH* stand for the differences in lightness, saturation and hue, respectively.

The initial data plots did not show a clear relationship between conspicuity and ΔE* as defined by eq. (1). We assigned a weighting factor to each of the three components ΔL* (lightness), ΔC* (chroma) and ΔH* (hue) in the calculation of ΔE*. When optimizing the hypothesized correlation between conspicuity and ΔE* with respect to these weighting factors, it turned out that the weights for components ΔC* and ΔH* were set to zero. This means that the colour choice or saturation apparently does not contribute to the aircraft conspicuity. When comparing the measured conspicuity values of the coloured airplanes with those of grey airplanes of the same luminance, no significant difference was found. This resulted in a reduced difference measure representing only the difference in lightness between the airplane and its background.

The regression line shown in Fig. 4 is given by

$$\text{conspicuity} = -9.24 + 28.5\, Log(\Delta L^*) \qquad (2)$$

Based on this regression line it is possible to predict the conspicuity of the PC-7 aircraft at 1 km distance for different colour schemes seen against different background lightness values (Fig. 5). Shown in Fig. 5 are the predicted conspicuities for a white, black and the current (mainly yellow) colour scheme. These predictions show that for light backgrounds a black airplane would be most conspicuous, and vice versa. But also, given certain background lightness, the gain or loss in conspicuity for alternative colour schemes (relative to the current colour scheme) can be estimated. For example, when the background lightness is 75, the conspicuity of the black colour scheme would increase with some 20 degrees relative to the current colour scheme. This would imply that a pilot scanning the air for other airplanes would detect the black airplane earlier, leaving more time for identification, course estimation and course changes. The lightness of the currently applied yellow colour scheme is about 90, which explains the minimum in the predicted conspicuity at background lightness of 90.

Discussion

As stated in the Introduction, the current research focussed on the conspicuity of the airplane at a fixed distance, and in a static situation. Conspicuity, here defined as the maximum angle that can be looked away from the airplane while still being able to detect it, is only part of the complex problem of airplane visibility. Numerous other factors, such as the angular size, speed, direction of the airplane, field of view from the cockpit, weather and lighting conditions, all contribute to the chances of being detected. However, it is clear that a high conspicuity is beneficial for the see-and-avoid principle.

The sooner an airplane is detected in the visual periphery, the more time is left for possibly necessary actions. The results of the current study indicate that the optimal colour scheme is dependent on the background lightness against which the airplane is seen. When the background lightness is not constant, the optimal colour scheme would have to change accordingly. This is not possible, but it is not difficult to create an internal contrast on the airplane, for instance using black and white to ensure visibility against any background lightness. Black and white would be logical colour choices also from the viewpoint of atmospheric contrast reduction. A matte black, and a glossy white would create maximum contrast on the airplane, but may nevertheless be considerably reduced by the atmosphere.

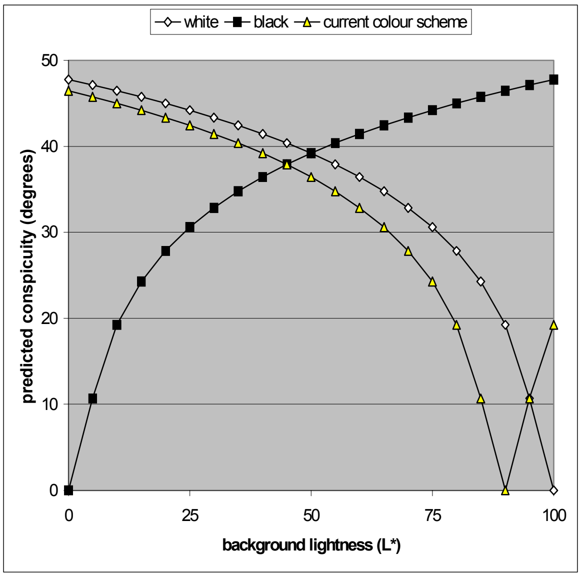

Figure 5. Based on the regression line defined in eq.(2), the conspicuity of three different colour schemes against all possible values of the background lightness is predicted.

Conclusions

In order to maximize the conspicuity of the PC-7 the difference in lightness between the airplane and its background should be made as large as possible. The colour choice (hue) does not seem a significant factor. For a predominantly light background a black PC-7 would be most conspicuous, whereas for a mainly dark background a white PC-7 would be most conspicuous. If both light and dark backgrounds are expected, both black and white could be used to create an internal contrast on the aircraft. These results only apply to the aspect of detection of an airplane in the visual periphery, but not to the identification of it. Colour information could still be helpful in airplane identification requiring foveal vision.

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Biography

Marcel Lucassen received his M.S. degree in Technical Physics from the Twente University at Enschede (The Netherlands) in 1988 and a Ph.D. in Biophysics from Utrecht University in 1993. From 1993-1999 he worked at the Colorimetry department of Akzo Nobel Coatings on topics related to automated colour matching of car refinishing coatings. Since 1999 he has worked in the department of Perception at TNO Human Factors, mainly on applied colour vision research. He is an associate editor for Color Research and Application.