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Do people match surface reflectance fundamentally differently than they match emitted light?

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ABSTRACT

We compared matches between colours that were both presented on a computer monitor or both as pieces of paper, with matching the colour of a piece of paper with a colour presented on a computer monitor and vice versa. Performance was specifically poor when setting an image on a computer monitor to match the colour of a piece of paper. This cannot be due to any of the individual judgments because subjects readily selected a matching piece of paper to match another piece of paper and set the image on the monitor to match another image on a monitor. We propose that matching the light reaching the eye and matching surface reflectance are fundamentally different judgments and that subjects can sometimes but not always choose which to match.

1. Introduction

People are very good at determining the contribution of surface reflectance to the light reaching their eyes (Granzier, Brenner, & Smeets, 2009). The lawful relationships underlying this ability obviously do not hold for surfaces that emit light, for which the light reaching the eye can be quite independent of the illumination. Do people consider this? Are there fundamental differences between judgments about surface reflectance and judgments about emitted light? One reason to think that there may be, is that some subjects match patches on a computer screen differently when instructed to make them look identical in hue and saturation than when instructed to make them look as if they were surfaces painted in the same colour (Arend & Reeves, 1986; Cornelissen & Brenner, 1995; see Arend & Spehar, 1993 for similar findings when matching luminance). In those studies, subjects were instructed to treat the patches in different ways. The disadvantage of explicitly instructing subjects to match the colour in a different way is that subjects are encouraged to consider the context in a manner that they probably normally would not, as when asking people to judge the distance to an object in a picture, rather than the distance to the picture itself. Moreover asking subjects to judge the reflectance of simulated surfaces may be particularly confusing because even the stimulus itself is ambiguous (Hurlbert, 1999; Kraft & Brainard, 1999). Several colour vision scientists have therefore designed ingenious systems for presenting surfaces of whatever colour they want within a seemingly natural environment, either by separately illuminating one object (e.g., De Almeida, Fiadeiro, & Nascimento, 2004) or by embedding a monitor screen within a scene in such a manner that it is impossible to see that it is not a real surface (e.g., Hansen, Walter, & Gegenfurtner, 2007; Nascimento, de Almeida, Fiadeiro, & Foster, 2005). Such precautions are taken to ensure that subjects treat the critical surfaces as real surfaces. But do subjects really treat reflected and emitted light differently when such precautions are not taken? Do they switch from evaluating a surface's reflectance to evaluating the composition of the light reflected to the eye when it is apparent that the surface is not real?

We recently found that subjects make better colour matches when real surfaces had to be matched in colour and luminance by selecting the appropriate sample from a colour selector (real coloured papers), than when they had to be matched with a surface on a computer monitor (Granzier, Smeets, & Brenner, 2006). A possible explanation for this is that the simulated surface on the computer monitor was treated fundamentally differently than the real surfaces. However, as mentioned above, the image on the screen is ambiguous when interpreted as a reflecting surface, so the poorer performance may just be a consequence of this ambiguity. If a fundamental distinction is made between light emitted by a monitor and light reflected by a surface, and subjects can judge both independently, subjects should be better at matching the colours of two images on computer screens and at matching the colours of two real surfaces, than at matching a real surface's colour with that of an image on a computer screen. If emitted and reflected lights are treated in the same manner, there need not be a fundamental difference between real and simulated surfaces. However, if this processing is more than just measuring the light reaching the eye, trying to dissociate between reflectance and illumination is likely to introduce additional variability for any match that

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involves images on a computer screen, especially when the surfaces that are to be matched are under different (simulated) illumination. Here we test all four possible combinations of the ways in which reference and matching colours can be presented. In contrast with the above-mentioned studies in which care was taken to prevent subjects from realising that some surfaces emitted light (Hansen et al., 2007; Nascimento et al., 2005) we did our best to ensure that it was always completely clear whether a surface reflected or emitted light. In contrast with our own previous study (Granzier et al., 2006) we used the same illumination for all surfaces. The light reaching the eye from the reference when it was presented on a computer screen was also the same as the light reflected from the reference when it was a piece of paper. This means that matching the light reaching the eye would also match surface reflectance if this were carried out in the same manner for both kinds of reference, so we can expect to find settings within the same region of colour space for all comparisons unless people match reflected and emitted light fundamentally differently.

2. Methods

The experimental room was split into two parts. Further from the subjects was a region in which the 'reference colours' (i.e. the colours that had to be matched) were presented. Nearer to the subjects was a region in which subjects matched the reference colours. The walls of the room were black. The reference colours were either presented as real coloured papers ('reference paper') or as colours on a calibrated computer monitor ('reference monitor'). The reference was either matched by selecting a real surface of an appropriate colour (from a 'colour selector') or else by setting the matching colour on a second calibrated computer monitor ('adjustable computer monitor'). Many colourful common household objects (such as a waste paper basked, a towel and a cup) surrounded the reference monitor. The reference monitor was about 5 m from the subject. When the reference was a piece of paper it was placed about 3.5 m from the subject, between the subject and the monitor, so that the same lamp illuminated the paper and the other objects (see Fig. 1). The reference paper was held in position by a clip of the kind used to hold photographs. The experimenter placed it manually. It was not placed extremely precisely, and the subject's head was not fixed, but subjects were instructed to maintain a head position for which the reference paper more or less occluded the screen of the computer monitor. The small difference in alignment across trials could have some influence on local contrast, perhaps slightly increasing the variability between trials when matching the reference paper. Part of the white borders of the monitor was visible so that the directly surrounding colours were about the same when the reference colour was presented on the monitor as when it was a piece of paper. The dimensions of the reference paper did not correspond precisely with those of the reference colour presented on the computer monitor, and the paper was clearly closer, so that it was always completely clear that it was a real piece of paper. Thus, subjects were always aware of whether the reference colour was being presented as a self-luminous patch (computer monitor) or as a reflecting surface (paper). During presentations in which subjects had to match reference papers the reference monitor was off.

2.1. The reference papers

There were only six reference colours, but subjects were not aware of this. The coloured papers were A4 format (29.6 × 21.1 cm). Under daylight illumination they looked green, pink, purple, light blue, dark blue and white. Under the lamp that we used to illuminate the scene the reference papers reflected light with 1931 CIE_{xyY} coordinates (0.420, 0.486, 5.77 cd/m^2), (0.518, 0.365, 7.25 cd/m^2), (0.452, 0.405, 11.6 cd/m^2), (0.430, 0.416, 11.1 cd/m^2), (0.346, 0.389, 12.1 cd/m^2) and (0.456, 0.417, 14.9 cd/m^2).

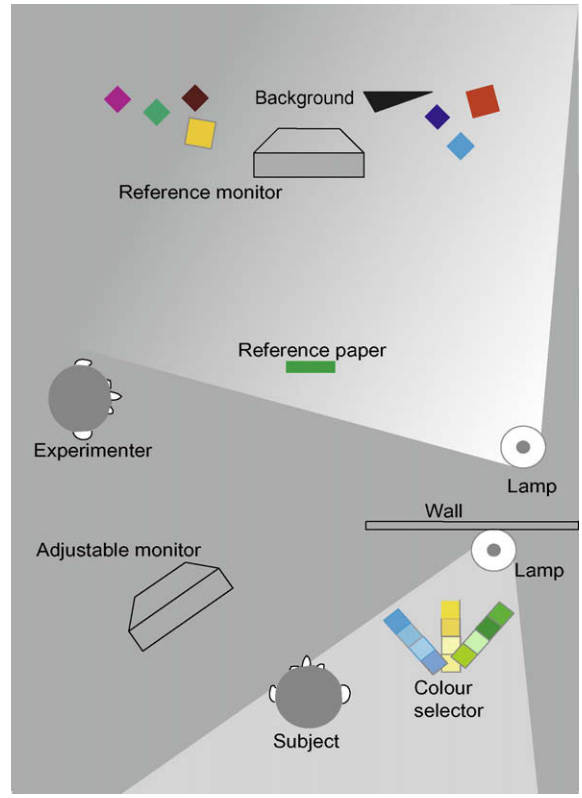

Fig. 1. Schematic overview of the experimental room. Subjects sat 5 m from the reference when it was presented on the computer monitor and 3.5 m from the reference when it was a piece of paper. The reference monitor was embedded in a background of common household objects. A single lamp illuminated the whole scene. Subjects either matched the reference colour with the colour selector or with an adjustable patch on a computer monitor.

2.2. The reference monitor

When the reference was presented on the computer monitor the whole monitor screen was filled with the reference colour. The reference monitor had an effective image size of 32 cm × 23 cm (1280 × 1024 pixels; 85 Hz; 8 bits per gun). The lamp that illuminated the background (and the papers when the reference papers were used) also illuminated the monitor, so we conducted the calibration (using a Minolta CS-100A chroma meter) with this lamp on. This allowed us to select reference colours on the monitor such that the light that reached the subject' eyes was as close as possible to that reflected by the six pieces of paper (see values above; the median error expressed as a distance in CIE_{xy} was 0.01; the median error in luminance was 0.6%). In these cases the light reaching the eyes was a combination of emitted and reflected light. The outer edges of the computer monitor (white plastic) were 4.5 cm wide.

2.3. The colour selector

For colour matching using real papers we used a colour selector (Pantone, New Jersey, 1984). Subjects had to select the sample that best matched the colour and luminance of the reference. Subjects were free to leaf through the pages until they found a suitable sample. Once they had found a good match, subjects read out the num-