Modelling the conspicuousness of small colored symbols

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If areas of color are very small then standard color-difference equations do not apply and small-angle models should include intraocular scattering of light and retinal-cone topography.

Is there anything useful that can be said about color? Personal appliances such as cell phones, global-positioning satellite-navigation devices, personal digital assistants, hand-held computers, and digital books use color to direct attention to small symbols and icons. But color and attention are subjective, and seemingly not susceptible to mathematical theories used by engineers and display designers. The possibility of color quantification is suggested by color-difference equations used to match paints, textiles, and other materials. If a small color difference represents a match, then perhaps a large offset indicates a conspicuous difference.

Although modern color-difference equations were not designed to predict the ability of color to capture attention, they do so very well. This success is encouraging, yet a difficulty remains: size matters. Color-difference equations are parametrized based on human perception of large fields of view, for instance painted walls and clothing (e.g., suits, not bikinis). If we think of 360° as a full viewing circle, then there are standardized color-difference equations for 2° or 10° fields of view. Artists use their thumb joint held at arm’s length to estimate 2°. Unfortunately, the equations become misleading for the small symbols and icons on personal appliances, which often subtend half a degree or less. Figure 1 shows human-performance data expressed as 1/(search time, in seconds) versus standard color-difference (CIEDE2000: ΔE, where E quantifies Empfindung or ‘sensation,’ as defined in 2000 by the International Commission on Illumination, CIE) estimates between targets and distractors. CIEDE2000: ΔE is the standard color difference, as defined in 2000 by the International Commission on Illumination (CIE), with larger numbers indicating larger differences between colors.

Figure 1. How fast can users spot a small symbol? The speed of a visual search (vertical axis: the highest points were found fastest) depends strongly on the size of the area (shape of the data point: solid black squares were larger than open white squares), and weakly on the difference in colors between the symbol and distractors. CIEDE2000: ΔE is the standard color difference, as defined in 2000 by the International Commission on Illumination (CIE), with larger numbers indicating larger differences between colors.

large objects. If so, we could use our understanding to extend color-difference quantification from macro to micro scales. One important factor affecting color appearance of small symbols is dispersion of light within the eye, the ‘point-spread function.’ Points of light, or small symbols that approach points in subtense, are diminished in intensity when their light is spread by the intraocular media. This has been studied in some detail and expressed in rigorous mathematical form. It is unimportant for appearance of most large visual fields, unless high intensities produce glare or retinal burning.

Another factor peculiar to small visual targets is undersampling by color-sensing cells on the retina at the back of the eyeball. These cells are of three types, sometimes referred to as red, green, and blue (R, G, and B), although they are each sensitive to a broad spectrum. For example, the average

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angular distance between blue-sensing cells in the retina is about one-sixth degree, and the central one-third degree of the line of sight is devoid of blue-sensing cells. As one would expect from this sparse sampling, people are increasingly insensitive to blue-yellow color differences as the objects they view are made smaller. Although red- and green-sensing cells are packed more densely, the color perceptions they mediate are similarly (if less dramatically) susceptible to fading as visual targets are made smaller.

For each of the three color channels and for each small angle (α), our model assumes intraocular scattering and attenuation of symbol differences of light intensity from the neutral background (R_n, G_n, and B_n): c_a (R−R_n), for example, where c_a < 1. The light scattered into (or out of) the symbol is added to (or subtracted from) the initial intensity. The resulting light intensity is further attenuated through undersampling by the color-sensitive cells: k_a [R ± c_a (R−R_n)]. Attenuation coefficients c_a and k_a are taken from previously published literature about intraocular light scattering and physiological color primaries.

We have developed a simple model based on these two factors. It enables diverse, modern color-difference equations (based on physical measurements of light) to predict apparent color differences in the range from 2 to 1/8 degree. To the extent that the model is successful, it suggests a research agenda for refining our knowledge of the two factors. Of course, in the interim, the 0.8 correlation between the model and human performance in a color-coded search task (an improvement with respect to Figure 1, for the same data) invites consideration by display designers.

Perhaps something useful can be said about color after all. If so, then it will be relevant not only to color coding of small symbols on hand-held devices, but also to the design of signal lights, emergency markers, photographic images, illuminants, and other displays (e.g., medical, astronomical, weather, industrial-process, military) that produce areas of color smaller than a few degrees of visual arc. We will continue to develop these ideas and hope to be stimulated to further research by colleagues at a forthcoming SPIE meeting.

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References