An intuitive color-selection tool

PM Henry, S Westland and TLV Cheung, Centre for Colour Design Technology, University of Leeds (UK)

Abstract

A color-picker or color-selection tool is part of a GUI that allows users to select colors for use in software applications. There is a widespread belief that some color spaces or models are more "natural" than others. However, this intuitively appealing idea that a color space based on the nature of color perception (such as HSL) may be preferable to one that is driven by the nature of the technology (such as RGB) has not been confirmed by all studies. In this paper we argue that it is not the color space per se *that is the most important factor underlying the usability of a color-selection tool but rather the color-mixing algorithm. An experiment was conducted to determine matching performance in a color-selection tool where the sliders interacted with the on-screen color using either a direct additive model or an indirect subtractive model to control the RGB values of the on-screen color. When observers were given a limited amount of time to use the sliders to match target colors their performance was statistically superior when they used the subtractive CMY sliders than when they used the additive RGB sliders. This is consistent with some previous work that suggests that observers possess better internal models of subtractive mixing than additive mixing and that the design of color-selection tools could exploit this. It should be noted that this work differs from some related work that has looked at the influence of color space on the usability of color-selection tools. Our hypothesis is that it is the color-mixing model that relates the slider bars to the on-screen color that is important rather than the choice of color space itself.*

Introduction

A color-picker or color-selection tool is part of a GUI that allows users to select colors for use in software applications. A number of studies have considered whether the choice of color space affects the usability of such tools[1-4]. There is a widespread belief[2] that some color spaces or models are more "natural" than others. For example, one established text[5] claims that "The RGB, CMY, and YIQ models are hardware oriented. By contrast, … HSV … is user-oriented, being based on the intuitive appeal of the artist's tint, shade and tone". However, this intuitively appealing idea that a color space based on the nature of color perception (such as HSL) may be preferable to one that is driven by the nature of the technology (such as RGB) has not been confirmed by all studies. For example, Douglas and Kirkpatrick concluded that choice of color space (specifically, in this case, comparing RGB and HSL) was not an important factor in the usability of a color-selection interface[2]. In this paper we argue that it is not the color space *per se* that is the most important factor underlying the usability of a color-selection tool but rather the color-mixing algorithm. The use of RGB sliders as part of a color-selection tool is essentially a color-matching task (where the user is additively combining primaries to match a target color) and therefore the user must have knowledge about the additive-mixing properties of the primaries controlled by the sliders. In a previous study we showed that users are better able to predict the results of subtractive color mixing than they are additive color mixing[6]. Users may possess well-developed internal models of subtractive color-mixing processes that developed in childhood as they experimented with inks and paints. A typical user, for example, would not be surprised to be informed that yellow and blue inks mixed together make green but may not be so familiar with the fact that red and green lights can be added together to make yellow. In this work, user performance in color-selection tasks is measured and compared for color-selection tools that are based upon additive and subtractive color mixing.

Method

A graphical-user interface (GUI) was created in MATLAB that enabled observers to adjust a color by adjusting each of three slider bars (see Figure 1). Users were instructed to adjust a sample color so that it was a visual match for a target color and were given a fixed amount of time to complete the task. Two time limits were employed: 120 seconds and 30 seconds. A total of nineteen observers were recruited to take part in the experiments but three were discarded because they displayed abnormal color vision. Six observers (3 male, 3 female) with normal color vision took part in the 120-second experiment. A different set of 10 observers (5 male, 5 female) with normal color vision took part in the 30-second experiment.

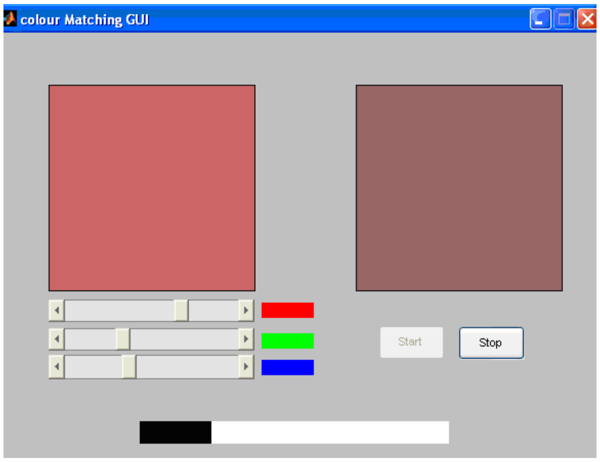

***Figure 1**: MATLAB GUI for color selection. The left-hand color is adjusted by the sliders to match the right-hand one. The bar at the bottom indicates the time remaining for the task.*

In the experiments, a total of 12 target colors were presented in turn in the right-hand part of the display (see Figure 1). The RGB values of the target colors are given in Table 1. The first three of these were for training purposes only to allow users to get used to the slider bars. The accuracy of the matching task for the first three colors in Table 1 was therefore not considered and results were calculated for the remaining nine target colors.

Table 1: sRGB specifications of color targets used in the experiment.

target	R	G	B
1 (training)	180	180	180
2 (training)	140	80	90
3 (training)	255	255	255
4	244	207	54
5	91	188	180
6	244	161	77
7	94	141	69
8	220	103	75
9	170	97	180
10	122	111	177
11	115	180	127
12	236	142	70

The experiment was conducted for two types of slider bars. The first type, RGB, controlled the RGB values of the sample patch directly and enabled the full gamut of the display (RGB $\in$ {0 … 255}) to be displayed. The second type, CMY, controlled the amounts of three arbitrary theoretical subtractive primaries. A simple Kubelka-Munk model was used to convert the amounts of the primaries into spectral reflectance factors for the subtractive mixture denoted by the sliders at any one time.

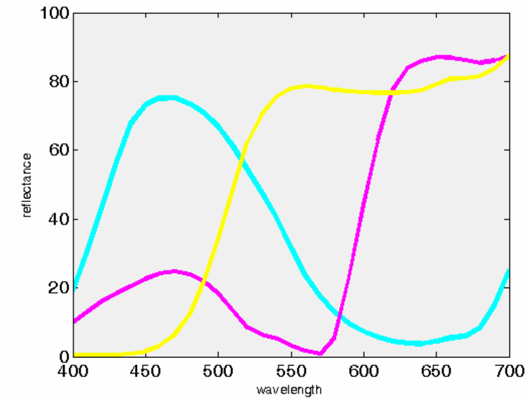

***Figure 2**: Reflectance factors for CMY primaries. These curves were obtained by measurement from a Xerox Phaser 7300 printer.*

Figure 2 shows the spectral reflectance factors of the CMY primaries at unit concentration. At each wavelength the reflectance factors were converted to K/S values using the equation $K/S = (1-R)^2/2R$. The slider bar values were mapped onto colorant concentration (in the range 0-1) for each of the CMY primaries and the K/S of the mixture calculated by summing the K/S values at unit-concentration each weighted by the concentration denoted by the slider bar. The inverse Kubelka-Munk equation was then used to predict reflectance at each wavelength, thus $R = 1 + K/S - ((1+K/S)^2 - 1)^{0.5}$. The predicted spectral reflectance was then converted to CIE XYZ under illuminant D65 for the 1964 CIE observer and finally the XYZ values were converted into sRGB values. In this way, the CMY sliders indirectly controlled the RGB values of the sample patch via a subtractive model of which the user was unaware. We feel that the choice of the primaries and even the nature of the Kubelka-Munk model are relatively unimportant for this experiment. The important difference between the RGB and CMY sliders is that the former is based on additive mixing whereas the latter is based on subtractive mixing. Thus, whereas increasing the intensities of the RGB sliders would increase the brightness of the sample patch, increasing the intensities of the CMY sliders would decrease the brightness of the sample patch. Another example would be that increasing both the red and green sliders in the RGB case would create a yellow sample patch, increasing the cyan and magenta sliders in the CMY case would create a dark blue. Our hypothesis is that is users do indeed possess a more intuitive understanding of subtractive mixing than they do of additive mixing then their performance in the CMY case would be better than in the RGB case.

In preliminary experiments the values (in the range 0 - 1) from the CMY sliders bars were directly mapped to CMY concentrations in the range 0 - 1. However, the non-linear relationship between concentration and XYZ resulted in several undesirable properties. Specifically, moving the CMY sliders had almost no visible effect on the colour on screen until they reached almost the half-way mark of their full range. Therefore, for the slider bar values were mapped to CMY concentrations using power functions with exponents 2.7, 1.8 and 3.4 for the C, M and Y respectively. These exponents were chosen so that when all three sliders were at the 0.5 position a mid-grey resulted on the screen which was close to R=G=B = 128.

It should be noted that the use of the Kubelka-Munk model in the CMY sliders did not allow the full gamut of the monitor to be explored. Therefore, the 12 target color samples (see Table 1) were selected partly so as to be within both the monitor gamut and the subtractive-primary gamut.

Performance was assessed by computing the CIE XYZ values of the target and final sample patches and then computing CIELAB and CIEDE2000 color differences. The RGB values of the target and sample patches were converted to XYZ values using a monitor characterization model.

Results

The accuracy of matching in the 120-second experiment is shown in Table 2. It can be seen that in terms of CIELAB color differences observers were achieved an average performance of 4.45 and 4.49 for the RGB and CMY sliders respectively. The differences were statistically not significant at the 5% level using a Wilcoxon signed-rank non-parametric test.

The accuracy of matching in the 30-second experiment is shown in Table 3. It can be seen that in terms of CIELAB color differences observers achieved an average performance of 24.88 and 11.34 for the RGB and CMY sliders respectively. The differences were statistically significant using a Wilcoxon signed-rank non-parametric test at the 5% level (and even at the 10% level).

Table 2: Results of color matching in 120-second experiment.

observers	CIELAB ΔE		CIEDE2000	
	RGB	CMY	RGB	CMY
a	4.47	**4.38**	2.34	**1.93**
b	**4.07**	4.79	**2.25**	2.09
c	**3.48**	4.39	**1.78**	1.94
d	5.32	**4.13**	2.22	**1.82**
e	5.19	**4.70**	2.44	**2.33**
f	**4.18**	4.54	**1.93**	1.94
average	4.45	4.49	2.16	2.01
p	> 0.05		> 0.05	

Table 3: Results of color matching in 30-second experiment.

observers	CIELAB ΔE		CIEDE2000	
	RGB	CMY	RGB	CMY
1	20.21	**9.32**	8.90	**3.88**
2	36.18	**11.23**	18.30	**7.37**
3	21.02	**10.38**	7.93	**5.20**
4	26.92	**14.83**	10.17	**6.65**
5	15.21	**8.23**	7.01	**4.30**
6	**8.50**	12.67	**3.64**	5.70
7	54.22	**13.09**	23.46	**5.85**
8	28.75	**15.30**	13.46	**7.65**
9	10.62	**7.23**	4.53	**3.53**
10	27.18	**11.17**	9.43	**6.80**
average	24.88	11.34	10.68	5.69
p	< 0.05		< 0.05	

Note that of the 10 observers that took part in the 30-second experiment, only 1 performed better using the RGB sliders whereas 9 performed better using the CMY sliders. In the 120-second experiment the matching performance is similar for the RGB and CMY sliders. This is because, given enough time observers will eventually achieve good matches whether they find the sliders particularly easy to use or not. The time-restricted task – at 30 seconds – is necessary to differentiate between the two sets of sliders. We therefore conclude that performance is better using the CMY sliders than using the RGB sliders and this supports the notion that observers have a better internal model for subtractive color mixing and that the design of color-selection tools could exploit this. We note that the same conclusions are reached whether the results are analysed in terms of CIELAB or CIEDE2000 color differences.

However, it is clear that the experiment did not isolate the effect of additive and subtractive mixing since the primaries used in the additive and subtractive system were very different. This makes it hard to argue that a color-selection tool based upon subtractive mixing is superior to one based on additive mixing since the effect of choice of primary may be dominant. The experiment was therefore repeated using a different set of subtractive primaries. Figure 3 is a chromaticity diagram that shows the sRGB gamut (red line) and the CMY gamut (magenta line). We devised a new set of subtractive primaries that were red, green and blue. Their gamut is illustrated in Figure 3 by the blue line. The reflectance factors of the subtractive RGB primaries were obtained by measurement from samples printed using the Xerox Phaser 7300 printer.

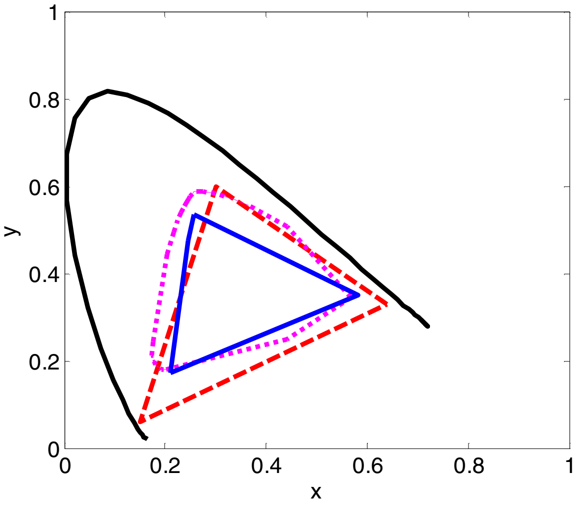

***Figure 3**: CIE chromaticity diagram showing the gamuts for the sRGB primaries (red line), the CMY primaries of the Xerox Phaser 7300 printer (magenta line) and the subtractive RGB primaries (blue line).*

The experiment was repeated using the RGB additive slider bars as before but replacing the CMY subtractive slider bars with RGB subtractive primaries. Six observers took part in this experiment and the results can be seen in Table 4.

Table 4: Results of color matching in 30-second experiment.

observers	CIELAB ΔE		CIEDE2000	
	RGB	RGB_S	RGB	RGB_S
i	23.94	**15.08**	15.93	**9.66**
ii	16.65	**12.13**	9.59	**7.62**
iii	**11.99**	12.02	**6.83**	7.44
iv	23.02	**14.29**	12.75	**8.97**
v	24.02	**9.92**	**14.50**	**6.44**
vi	**9.76**	10.58	**5.59**	7.85
average	18.23	**12.34**	10.86	**8.00**
p	< 0.05		< 0.05	

Again, statistically better performance was obtained using the subtractive system (denoted as RGB_S in Table 4) than using the additive system (denoted as RGB). It is disappointing, however, that the agreement between the additive RGB primaries and the subtractive RGB primaries (see Figure 3) was not closer since it could still be argued that it is the choice of primaries (and their resultant gamuts) that determines performance rather than the additive or subtractive nature of the mixing model. Nevertheless, there is strong evidence that users make more accurate matches in time-restricted tasks when using slider bars that control a subtractive-mixing system than when using slider bars that control an additive-mixing system. Further work is required to confirm the hypothesis that the more intuitive nature of subtractive mixing is a critical component of color-selection GUI design.

Conclusions

An experiment was conducted to determine matching performance in a color-selection tool where the sliders interacted with the on-screen color using either a direct additive model or an indirect subtractive model to control the RGB values of the on-screen color. When observers were given a limited amount of time to use the sliders to match target colors their performance was statistically superior when they used the subtractive CMY sliders than when they used the additive RGB sliders. This is consistent with some previous work[6] that suggests that observers possess better internal models of subtractive mixing than additive mixing and that the design of color-selection tools could exploit this. We note that in practical terms it is probably not especially important whether a user can achieve a match in a color-selection tool in 3 seconds or 5 seconds. However, we argue that creative workers will prefer to work with tools with which they feel comfortable and that the use of such tools will complement rather than hinder the creative process. The accuracy to which an observer can make a match given a limited amount of time can reasonably be used as an indicator as to whether a particular tool is likely to be comfortable for a designer working in the digital domain.

It should be noted that this work differs from some related work that has looked at the influence of color space on the usability of color-selection tools. Our hypothesis is that it is the color-mixing model that relates the slider bars to the on-screen color that is important rather than the choice of color space itself. In other to further support this hypothesis, an additional experiment was carried out to compare an additive RGB slider bar model with a subtractive RGB slider bar model. Performance in the 30-second task was better in the subtractive case than the additive case even though both were based on RGB systems.

References

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Author Biography

Phil Henry is a Teaching Fellow at the University of Leeds. He is currently working towards a PhD in the Centre for Colour Design Technology at Leeds University.