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The role of gamut, intuition and engagement in colour management in a design context

Phil Henry and Stephen Westland

School of Design, University of Leeds (UK)

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Colour management is ubiquitous in the digital world. However, despite the many advances in colour management over the last couple of decades, it remains an imperfect process. In the art and design community there is often a level of dissatisfaction and deep cynicism about colour management that can lead to lac of engagement with the process. This research explores colour management in a design context though three issues: the *gamut issue*, the *intuitive issue* and the *engagement issue*; each relates to areas where colour management could better connect with tacit design knowhow. The work focusses on the selection of colour in a digital context since for many users this is the first touch point that they have with colour management. Psychophysical studies have been carried out in both laboratory and design-studio settings. It is shown that users can better predict the results from subtractive colour mixing than from additive colour mixing. The performance of various types of colour picker are explored and consequences for the design of user interfaces are discussed.

Introduction

Colour management is the process of adjusting colour representations of different devices to achieve colour fidelity and has been discussed widely in the literature [1-3]. In modern colour-imaging devices, from smart phones to digital cinema, it is ubiquitous. Colour management in a professional context is normally implemented through ICC colour profiles which typically require some user knowledge and intervention [4]. However, in the default situation where a user effectively 'does nothing' some level of colour fidelity is still achieved because of the widespread adoption of the standard colour space known as sRGB [5]. Meanwhile, in research laboratories more complex non-linear transforms are sometimes used to obtain high levels of fidelity but which require a level of expertise that typically exceeds that of the average professional worker in art and design [6].

Even the expertise required to implement ICC-based colour management is typically challenging for artists and designers who are not experts in colour science and/or digital technology [7-10]. Lack of CAD expertise in the areas of colour control is still shown to be a barrier to the successful adoption of design technology amongst small entrepreneurial design businesses [11]. A recent study provided striking insights into the complex challenges of navigating colour management protocols, drawing attention to the limitations of conventional colour management processes in the areas of gamut evaluation and profile generation [12]. This work was triggered by observations that designers' learnt colour knowledge is a type of expertise that does not easily transfer into a standard digital domain.

All practical colour-image reproduction devices have a limited colour gamut. Typically there can be a mismatch between display and print devices; some colours can be achieved on screen but are outside of the gamut of the printer and vice versa. Rendering intents can be utilised to instruct the colour-management software how to handle a mismatch between a source and destination gamut. However, novice designers sometimes struggle to work effectively in source and destination colour spaces. Typically, for example, they will choose colours on screen that cannot be colorimetrically reproduced in print. Previous studies suggest that users perform better in simple colour-matching tasks if the colour-picker interface design is natural [13-14]. Perhaps designers would be able to overcome the 'gamut' issue if the colour management tool enabled them to better utilize tacit colour knowledge of subtractive colour principles? Designers frequently interact with colour-management systems through a colour picker graphic-user interface (GUI). It is as this point, where the user selects colours for use in a design, that issues relating to colour management often begin since, for example, selecting colours that are outside of the gamut of the destination device (e.g. typically a printer) will frequently lead to dissatisfaction in the final output. This can lead in turn to lack of confidence in the colour-management system and a subsequent lack of engagement. It is therefore at the point of using a colour picker that this study is focussed. Usability studies colour picker GUIs have often considered the speed and accuracy of user ability. Key factors that are highlighted within the studies include the importance of visual feedback, learning effects and performance analysis of the individual colour sensations of hue, lightness and brightness [15-17]. Contemporary sources consistently cite hue-based models (such as HSV) for colour-picker tools to be more natural as they relate to the established concepts of human vision and perception [18]. RGB models, conversely, are considered hardware-oriented and therefore psychologically non-intuitive because people do not think of colour in terms of amounts of RGB light. What is understood to be intuitive, with regards to the user's tacit colour knowledge is not generally considered.

The difficulties that face designers are addressed in this study through three issues which will be termed the *gamut* issue, the *intuitive* issue and the *engagement* issue. The gamut issue is the fact that the colour gamuts of the printer and the display will likely be different and sometimes it is not possible to reproduce in print the vivid colours that may appear on screen. Users who understand this issue may be less frustrated when using CAD systems for design. The intuitive issue is the notion that users may have a better intuitive understanding of, for example, subtractive colour mixing than of additive colour mixing. One of the ideas explored in this paper is that colour pickers based on subtractive-mixing principles may be easier to user for users. The engagement issue describes the problem that can occur where users fail to engage fully with the technology that underpins the colour-management system and this may lead to frustration and disappointment. Three experimental studies are described that address these issues and then the implications of the findings are discussed. Some components of the first two experiments have previously been published [19-20]; all three experiments are presented together for the first time to enable new insights.

Experimental

The ability to be able to predict the result of colour mixing is inherent to understanding the limited colour gamut of a small set of colour primaries. Experiment I was designed to test the hypothesis that participants, both expert and naïve, would be able to make effective colour predictions for mixing physical paint swatches (phase 1), subtractive mixtures on screen (phase 2) and additive mixtures on screen (phase 3). A separate set of 12 participants (6 who were classed as experts because they work in colour-critical professions such as textiles or fashion and 6 who were classed as naïve with only an informal awareness of colour issues) for each of the three phases. All participants were assessed as having normal colour vision and successfully passed the Ishihara colour test. In the first phase, participants were presented with pairs of physical paint panels and asked to predict the result that would occur if the two were mixed together in equal proportions. There were nine pairs in total (three of the pairs were combinations of the subtractive primaries cyan, magenta and yellow; the other pairs were for secondary and tertiary colours). For each pair, participants were asked to select the colour that they thought would result by choosing from a NedGraphics[1] colour atlas that was made available to them through printing with an HP8550 laser jet printer. The pairs were presented to the observers on a neutral grey background and were illuminated by a light source

[1] NedGraphics are a supplier of Computer Aided Design Software for Printed Textiles

approximating the CIE D65 daylight illuminant. Note that it was not the accuracy of the prediction that was of interest (since there was more than one correct prediction) but rather the consistency between the predictions made by the participants. The more similar the predictions made by the participants the more likely they share similar understanding of how paints mix together. In the second and third phases the ability of participants to predict the mixture of colours was assessed in a digital environment; the same colour pairs as before were replicated on a display that was characterized using the GOG model [2] to enable the colours to be displayed to be similar to the original paint samples. The original experiment layout from Phase 1 was replicated using NedGraphics Printing Studio Textile design software, as it allows a real-time manipulation of 'spot colours'. The participants were able to select their best-imagined mix-colours from the same NedGraphics printer atlas via a simple drag and drop interface. Apart from being a digital simulation the experimental details were kept as similar as possible to the first phase. However, in the second phase 12 observers predicted the subtractive mixtures of the nine colour pairs (replicating the first phase in the digital domain) and in the third phase a different set of 12 observers predicted the additive mixtures of the nine colour pairs. Performance was assessed by calculating the mean colour difference between each participant's colour selection and the average of all the participants' selections. The smaller the colour difference the more similar the colours chosen were and hence the more likely that the participants share a common understanding.

The hypothesis for Experiment II was that a 'natural' colour-picker GUI has the potential to better connect with a user's intuitive colour understanding of physical colorants. Two colour-picker tools are compared, one operating on additive-mixing principles and the other on subtractive-mixing principles. A colour-matching task was designed (created with MATLAB software) utilizing the two digital colour-picker tools, each with the same slider bar interfaces, but one operating on additive principles (mixing RGB) and the other on subtractive (mixing CMY). In simple terms, when the RGB model is used at 100% for each primary the resulting colour displayed is white and with the CMY model when all slider-bars are set to 100%, black is the on-screen result (see Figure 1). The objective was not to assess colour-matching ability *per se* but rather to evaluate participants' initiative understanding of the underlying colour models. To this end no information or visual clue was provided as to the operation of the either colour-pickers, none of the slider bars were labelled in any way. The only direct feedback a user was able to assess was the resultant colour that changed in real-time in response to their manipulation of the slider bars.

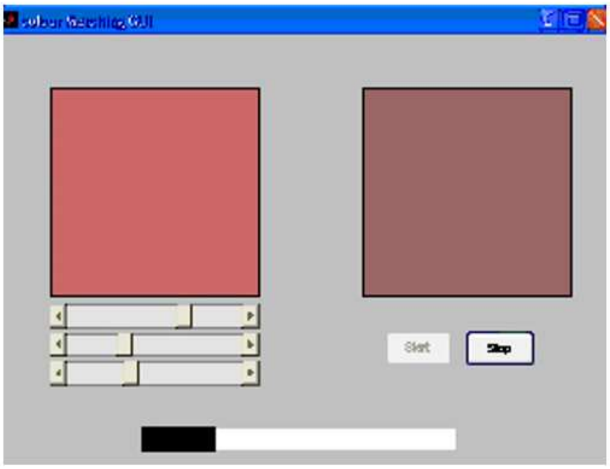

Figure 1: MATLAB GUI for colour selection. Participants used the slider bars to change the colour of the patch above the slider bars to visually match the colour of the patch on the right. The bar at the bottom of the GUI indicated the time available to complete the task.

Participants were instructed to use the slider bars to adjust a sample colour so that it was a visual match to a target colour 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 participants were recruited to take part in the experiments but three were discarded because they displayed abnormal colour vision. Six participants (3 male, 3 female) with normal colour vision took part in the 120-second experiment. A different set of 10 participants (5 male, 5 female) with normal colour vision took part in the 30-second experiment. Such a basic interface was used to avoid any positive effects from interface feedback or the intuitiveness associated with a hue or lightness attribute discussed in the experimental literature. The hypothesis was that if participants do indeed possess a more intuitive understanding of subtractive mixing than they do of additive mixing then their performance in the CMY (subtractive) phase should be better than in the RGB (additive) phase. When the additive model was implemented the slider bars simply controlled the intensities of the RGB primaries of the display. When the subtractive model was used the slider bars controlled intensities of imagined CMY primaries that were defined spectrally. A simple Kubelka-Munk model [3] was used to convert spectral reflectance factors R into Kubelka-Munk K/S values (K/S= (1-R)(1-R) /2R). The K/S values at each wavelength were assumed to be additive for the three primaries to predict the K/S values of the mixture and were linearly related to the concentration of the primaries (which was controlled by the slider bars). After each movement of any of the slider bars the K/S values of the mixture were calculated, summed at each wavelength, and converted back into spectral reflectance factors before being converted to CIE XYZ under illuminant D65 for the 1964 CIE observer and finally 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. The choice of the primaries and even the nature of the Kubelka-Munk model were relatively unimportant for this experiment. Participants were asked to match 12 randomly selected colour targets. The first three of these targets were used for training and the results were discarded. Performance in the additive and subtractive tasks was assessed by average CIEDE2000 colour difference between the target colour and the match colour for the nine colour targets.

In Experiment III, MATLAB was again used to create a digital experimental environment that incorporated four colour-picker GUIs. The RGB and CMY slider bar arrangements, as used in Experiment II, were used. In addition, a HCL slider bar arrangement and a colour interface (GUI) typical of the standard design used in generic design and word processing software and easy to learn qualities due to the prominence of visual colour feedback were also tested (Figure 2).

Sixteen undergraduate textile and fashion students from the University of Leeds participated with four taking part in each of four phases. The participants all possessed a working knowledge of digital colour tools, the basics of which will have been introduced as parts of their programme of study. However, their level of understanding was still at an early stage. The reason for using these participants was to embed the research within the practice of teaching undergraduate design students. The participants were presented with the four colour-picker arrangements in a random sequence, to avoid training effects. Each subject carried out a colour-matching exercise using all four colour-pickers, with a time limit of 30 seconds set for each colour match. Each participant was asked to match 12 colours in total using each interface; the first three in each case were discarded as practice trials and the accuracy of matching was averaged over the other nine colours. The objective of this experiment was to evaluate to what extent a better awareness of the related colour model, and the physical environment in which the activity takes place, will affect user performance.

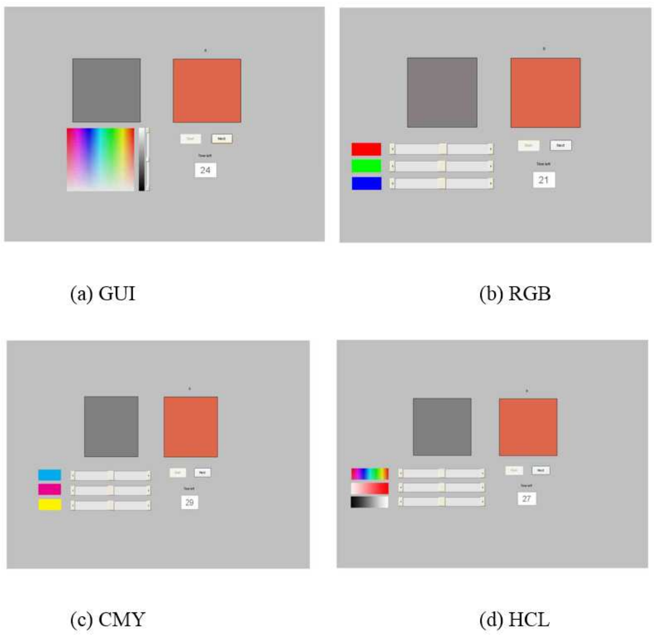

Figure 2: The colour-picker tools used: (a) a standard GUI arrangement found in numerous standard software applications such as Microsoft office, system; (b) an RGB slider bar arrangement consistent with earlier work; (c) a CMY slider bar again consistent with the experimental paradigm; (d) an HCL arrangement modelled on standard configurations.

The first phase of the experiment (with four participants) was conducted in a CAD (Computer Aided Design) studio, an environment familiar to the participating students. A design studio is recognised as an area where students are traditionally provided with the opportunity to learn through practical engagement and group feedback. Nassau has suggested that users' digital colour performance in the CAD studio may improve with sufficient education in colour theory [21]. In phase two, the studio-based colour-matching experiment was repeated with a new set of four participants; the key difference on this occasion is that they were first presented with an explanation of RGB and CMY. No time restrictions were given with regards to the study of the information (explanation of the relationship subtractive mixing principles and the physical process of paint-mixing) and any pertinent questions were answered. It was not considered that any in-depth explanation was needed for the HCL model beyond the slider bar functioning, or for the Graphical Colour interfaces as the visual information presented in the display was, on the one hand, familiar due to previous exposure and, on the other, to explain the intricacies of Colourfulness, Brightness and Chroma may have proved confusing, certainly in the context of a three-dimensional colour-space.

Table 1: Summary of the experimental work conducted.

Study	Details	Phase	Participants
Experiment I	Predicting colour mixing	Phase 1: physical paints	12
		Phase 2: subtractive mixing on screen	12
		Phase 3: additive mixing on screen	12
Experiment II	Colour matching using slider bars	Phase 1: 120s time limit	6
		Phase 2: 30s time limit	10
Experiment III	Colour matching using each of four GUIs (30s time limit)	Phase 1: studio without explanation	4
		Phase 2: studio with explanation	4
		Phase 3: lab without explanation	4
		Phase 4: studio with explanation	4

In the third and fourth phases of the experiment the work was repeated in a laboratory (rather than in a design studio) with and without explanation as before to explore the effect of the environment on user performance. Separate sets of four participants were used for each of these two phases. Table 1 is a summary of the three experiments that are included in this work.

Results and Discussion

Figure 3 shows a visual representation of the colours that were predicted by each of the 12 observers in the first phase of Experiment I for three of the nine colour pairs.

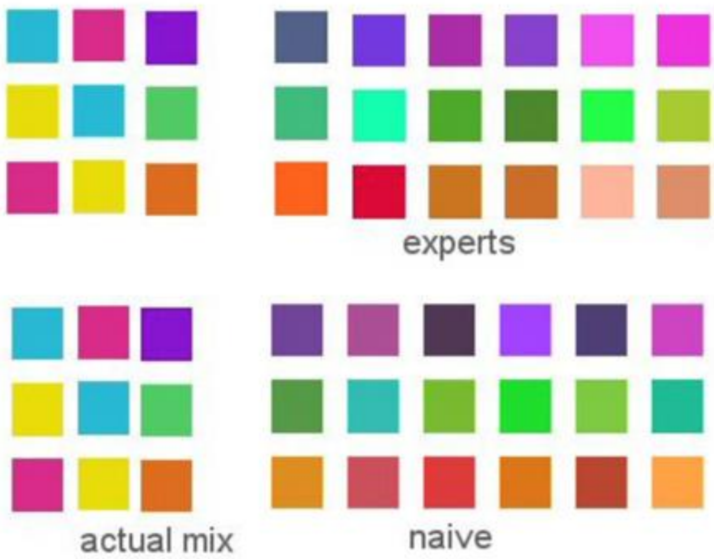

Figure 3: *Figure 3: Visual representation of observer variability in predictions for three pairs showing results for expert and naïve observers in the first phase. Columns 1 and 2 show the pair that was shown to the observers, column 3 shows the actual mixture of the physical paint samples (that was not shown to the observers), and columns 4-9 show the predictions made by observers (each column is a different observer).*

Although Figure 3 is interesting, in order to quantify performance for each phase the average colour difference using CIEDE2000 (ΔE_{00}) was calculated between each observer's predicted colour and the average colour predicted by all the observers (Table 2). This average colour difference is therefore a measure of consistency of prediction between the observers. For Phase 1 (predicting subtractive differences in the physical domain) the consistency of the expert observers ($\Delta E_{00} = 8.54$) was better than for the naïve observers ($\Delta E_{00} = 11.65$) but the difference was not statistically significant ($p > 0.05$). The observation that naïve observers can perform this task as well as experts is consistent with the idea that the ability to predict colour mixtures is a cognitive skill acquired through practice and learning, especially during childhood; the majority of early interaction with colour is likely to be with physical media such as paint and hence governed by subtractive theories.

When predictions from naïve and expert observers were pooled, there were two main findings. Firstly, that the consistency of predictions was better ($\Delta E_{00} = 8.54 < \Delta E_{00} = 12.31$), but not significantly so ($p > 0.05$), when observers worked in the physical domain (Phase 1) than when they worked in the digital domain (Phase 2). Secondly, that the consistency of predictions was better ($\Delta E_{00} = 12.31 < \Delta E_{00} = 15.02$, $p < 0.05$) when observers made subtractive predictions (Phase 2) than when they made additive predictions (Phase 3) in the digital domain. These results are summarised in Table 2.

Table 2: Mean CIEDE2000 (2:1) values for Phase 1, 2 and 3. Lower mean colour differences indicate greater inter-observer consistency.

	Mean	**Median**	**Max**
Phase 1 (Physical Samples)	8.54	8.39	12.28
Phase 2 (CRT Simulations)	12.31	13.21	20.54
Phase 3 (CRT Simulations additive mixes)	15.02	14.80	22.81

The observation that observers are more consistent at making subtractive colour predictions than they are at making additive colour predictions supports the hypothesis that observers possess less tacit knowledge for additive mixing than for subtractive mixing. One implication of this hypothesis is that software that uses a colour-picker tool based on subtractive mixing principles may be more intuitive than a similarly constructed one based on an additive model. The following section further explores this suggestion.

Experiment II explored the accuracy of colour matching under two time limits (120s and 30s) using slider bars using additive and subtractive principles. For 120 seconds (Table 3) it can be seen that average performance ΔE_{00} was 2.16 and 2.01 for the RGB and CMY sliders respectively. The differences were statistically not significant ($p > 0.05$) at the 5% level using a Wilcoxon signed-rank non-parametric test. For 30 seconds (Table 4) the average ΔE_{00} was 0.68 and 5.69 for the RGB and CMY sliders respectively ($p < 0.05$).

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. We suggest that 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.

Table 3: Mean colour differences over 9 colour targets using additive (RGB) and subtractive (CMY) colour models using the 120-second time limit.

	CIEDE2000	
Observers	RGB	CMY
A	2.34	1.93
B	2.25	2.09
C	1.78	1.94
D	2.22	1.82
E	2.44	2.33
F	1.93	1.94
Average	2.16	2.01
P	> 0.05	

Table 4: Mean colour differences over 9 colour targets using additive (RGB) and subtractive (CMY) colour models using the 30-second time limit.

Observers	CIEDE2000	
	RGB	CMY
1	8.90	3.88
2	18.30	7.37
3	7.93	5.20
4	10.17	6.65
5	7.01	4.30
6	3.64	5.70
7	23.46	5.85
8	13.46	7.65
9	4.53	3.53
10	9.43	6.80
Average	10.68	5.69
P	< 0.05	

Experiment III also explored colour matching but this time looked at the effect of having explanation (of the underlying colour model) or not and the effect of the environment (studio or laboratory). Results from Phase 1 (studio environment without explanation) showed the smallest colour differences (and hence best performance) was obtained with the HCL slider bar arrangement (Table 5). Despite the clear visual information offered by the GUI colour differences were higher using this (9.31) than with the HCL arrangement (7.74). CMY performed better than RGB as found in previous experiments. The variable sequence with which the participants used the four colour-pickers did not appear to affect the results for the CMY and RGB colour-pickers but there is some effect of order was found for the other two arrangements.

Table 5: Colour matching results for design studio (Phase 1) demonstrating that the most accurate matches are obtained with the HCL arrangement (smaller colour differences represent better colour-matching performance).

Phase 1: Studio no explanation				
Order of presentation	GUI (a)	RGB (b)	CMY (c)	HCL (d)
abcd	4.16	10.35	10.92	4.49
dabc	8.82	17.94	16.78	8.41
bcda	5.38	17.53	12.08	6.67
cdab	18.89	24.25	17.07	11.40
Average	9.31	17.52	14.21	7.74

Table 6: The provision of an explanation of the relationship between CMY colour space and paint mixing (Phase 2) is shown to improve performance (smaller colour differences represent better colour-matching performance).

Phase 2: Studio with explanation				
Order of presentation	GUI (a)	RGB (b)	CMY (c)	HCL (d)
abcd	14.08	6.05	5.62	7.085
bcda	13.47	17.00	14.46	11.20
cdab	10.48	19.73	14.25	17.24
dabc	6.079	21.15	6.54	6.69
Average	11.03	15.98	10.22	10.55

For Phase 2 (in the studio with explanation) the results from the RGB colour-picker still demonstrate this colour-space to offer the least intuitive user experience. Most notably, however, the performance of the CMY slider bars was comparable to the GUI and HCL arrangements. The observation that the individual results for the HCL and Graphical Colour interface are not as accurate as the results from the design studio with no explanation requires some consideration. One explanation may be that the participants were less focused on these two colour-pickers due to the attention given to RGB and CMY, however the varied sequence in which the colour-pickers were used would suggest that this is not the case. A heightened level of concentration may have caused the participants to, as Norman suggests, become more engrossed in the task, making a greater connection with the tacit colour knowledge at the expense of their perceptual awareness of the visual interfaces. This is difficult to assess under the current experimental conditions so, with this question in mind, both experiments were repeated with new participants in conditions that may invoke a more focused level of engagement than the familiar design studio.

When the work was repeated in the laboratory the CMY arrangement gave comparable results to the HCL and GUI arrangements both without (Phase 3) and with (Phase 4) explanation as shown in Tables 7 and 8 respectively. The RGB model was also shown to be consistent with the results from the other experimental work in that the participants found it to be the least intuitive, the hardest model with which to make colour matches.

Table 7: Colour differences obtained in the laboratory condition without explanation (Phase 3).

Phase 3: Lab no explanation				
Order of presentation	GUI (a)	RGB (b)	CMY (c)	HCL (d)
abcd	9.75	15.74	10.50	10.49
bcda	6.03	12.86	13.05	8.41
cdab	7.99	14.54	11.64	17.55
dacb	9.29	16.63	9.21	14.73
Average	8.26	14.94	11.10	12.80

Table 8: Colour differences obtained in the laboratory condition with explanation (Phase 4).

Phase 4: Lab with explanation				
Order of presentation	GUI (a)	RGB (b)	CMY (c)	HCL (d)
abcd	12.15	17.30	9.067	9.142
bcda	18.79	16.23	8.43	9.44
cdab	7.54	15.84	17.11	26.93
dabc	8.37	13.76	7.54	4.38
Average	11.71	15.78	10.54	12.47

Summary

Three experiments have been described in this paper. In the first experiment participants were asked to predict the results of additive and subtractive mixtures. It was shown that participants were able to make more consistent matches for subtractive mixing than for additive mixing. This suggests that observers possess less tacit knowledge for additive mixing than for subtractive mixing. In the second experiment participants used sliders bars to match on-screen colours where the slider bars responded in a way that was consistent with subtractive CMY or additive RGB mixing. It was shown that, when time was limited, participants made better matches when using the CMY subtractive slider bars than when using the RGB additive slider bars. This experiment, in conjunction with the first, suggests that not only do participants have a greater tacit knowledge of subtractive mixing than additive mixing but that this can be used to improve performance of a colour-picker GUI. In the third experiment, RGB (additive) and CMY (subtractive) slider-bar colour pickers were compared with two other colour pickers (one based on hue, chroma and lightness slider bars and one which was a GUI where participants could select the colour from a wide range of displayed colours). This work was done in two environments (a design studio and a laboratory and with and without explanation, resulting in four phases). In all four of these phases the RGB slider bars resulted in the worst colour matches. Although in one of the phases (Phase 1, the design studio without explanation) the

CMY slider bars gave worse performance than the HCL or GUI arrangements, in the other three phases the CMY arrangement gave performance that was comparable with, or even better than, the performance of the HCL and GUI arrangements that are found in many commercial software packages. The work in this paper, therefore, provides quite strong evidence that the use of CMY subtractive slider bars has potential for use in software colour-picker environments. It is suggested that the reason for this potential is that such an arrangement is capable of exploiting the tacit knowledge that users have for subtractive colour matching. Subtractive colour mixing is intuitive for users.

This study raises the question of why designers' tacit knowledge about the physical world and subtractive colour mixing cannot easily be transferred digital domain to drive their decision-making processes. One possibility is that the types of colour picker offered in many commercial software applications distort a users' colour expectations. If not otherwise directed, many users' seem to adopt a position of understanding steered by 'functional fixedness' [22]; subconsciously aligning the unseen potential of the subtractive printer gamut to the very visible and perhaps more appealing additive display gamut. One potential solution to this problem is offered which is to design colour pickers that explicitly make user of users' tacit knowledge. Just because digital displays operate using RGB primaries that function using an additive model there is no reason to enforce this way of thinking on to a user at the level of the user interface; doing so will often be non-intuitive for the user and risks lowering their engagement with the colour-management process.

References

[1] Sharma, A., 2018. Understanding Color Management (2nd edition), Wiley-Blackwell, ISBN 9781119223634.

[2] Berns, R.S., 1996. Methods for characterizing CRT displays, Displays, 16, 173-182.

[3] Westland, S., Ripamonti, C. and Cheung, V., 2012. Computational Colour Science: Using MATLAB (2nd edition), Wiley-Blackwell, ISBN: 0470665696.

[4] http://www.color.org/icc_specs2.xalter, International Color Consortium (last accessed 24 June 2019).

[5] Anderson, M., Motta, R., Chandrasekar, S. and Stokes, M., 1996. Proposal for a standard default color space for the internet—srgb. In Proceedings of the 4th Color and Imaging Conference, 238-245, Society for Imaging Science and Technology.

[6] Hirschler, R., Csillag, P., Manyé, P. and Neder, M., 2018. How much colour science is not too much?, Color Research and Application, **43** (6), 977-992.

[7] Treadaway, C., 2004. Digital Reflection; the Integration of Digital Imaging into the Creative Practice of Printed Surface Pattern and Textile Designers. PixelRaiders2, Sheffield Hallam University.

[8] Treadaway, C., 2009. Translating experience. Interacting with Computers Issue 21 Pages 88-94.

[9] O'Neill,J., Martin, D., Colombino, T., Roulland, F. and Willamowski, J., 2008. Colour Management is a Socio-technical Problem. Proceedings of CSCW 08.

[10] Hirschler, R., 2010. Electronic Communication in the Textile and Apparel Industry, REDIGE - V1 N1.

[11] Polston K., Parrillo-Chapman L., and Moore M., 2015. Print-on-Demand Inkjet Digital Textiles Printing Technology. International Journal of Fashion Design, Technology and Education, 8 (2), 87-96.

[12] Ding, Y., Parrillo-Chapman, L. and Freeman, H.S., 2017. Developing the Methodology of Colour Gamut Analysis and Print Quality Evaluation for Textile Ink-Jet Printing: Delphi Method, Coloration Technology, 143 (2), 134-147.

[13] Douglas S.A., and Kirkpatrick, A.E., 1996. Do Color Models Really Make a Difference? SIGCHI conference on Human factors in computing systems, Vancouver, British Columbia, Canada, 399 – 422.

[14] Douglas S.A., and Kirkpatrick, A.E., 1999. Model and Representation: The Effect of Visual Feedback on Human Performance in a Color Picker Interface, Proceedings of ACM transactions on Graphics. 18 (2), 96-127.

[15] Schwarz, M.W. and Beatty, J.C., 1987. An Experimental Comparison of RGB, YIQ, LAB, HSV and Opponent Models, Proceedings of ACM Transactions on Graphics, 6 (2), 123-158.

[16] Smith A.R. and Lyons, E., 1996. HWB-A More intuitive Hue-Based color Model, Journal of Graphic Tools, 1 (1), 3-7.

[17] Bauersfeld, P.F., and Slater, J.L., 1999. User-Oriented Color Interface Design: Direct Manipulation of Color in Context, ACM Transactions on Graphics, 18 (2), 96-127.

[18] Zhang, H. and Montag, E., 2004. How well can people use different color attributes? Journal of Vision, 4 (11), 95.

[19] Henry, P.M., Westland, S., Burkinshaw, S.M. and Cheung, T.L.V., 2005. How well can people predict subtractive mixing? Proceedings of the 13th Color Imaging Conference, 85-88.

[20] Henry, P.M., 2014. Colour-picker tools for design, PhD Thesis, University of Leeds.

[21] Nassau, K., 1998. Color for Science Art and Technology, Amsterdam, Netherlands. Elsevier Science B.V.

[22] Duncker, K., 1945. On Problem-Solving, Chapter in Dashiell J., F., ed., Psychological Monographs, 58 (5).