Does color-form correspondence exist for luminous stimuli?

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ABSTRACT: Color-form correspondence is explored with luminous stimuli. Two-dimensional forms are used to express seven chromatic colors and all combinations thereof, in three differing experiments of varying spatial complexity. The exploratory studies are motivated to bridge the worlds of art and science by offering insights to the perceived relation between chromatic light stimuli and form.

1. INTRODUCTION: There have been historically various attempts to resolve systematic relationship between form and color [1]. Such relationship can be understood as a means of linking the worlds of arts and science. Science is seen as an act of deconstructing and in turn defining order, while art is defined as something which is absorbed holistically. An artist however may implicitly use an underlying order to define a concept.

As for form in respect to color, a number of theories have been developed and tested [1]. In the early 1920's Kandinsky aimed to find a universal visual language by corresponding color and form. As Jacobsen [1] quotes, Kandinsky believed that a natural link between the two express a "synaesthetic quality". Correspondence found by Kandinsky in a yellow triangle, red square and blue circle were based rather on his feelings, in addition to his synaesthetic experiences, as opposed to scientific evidence.

In respect to color and its aesthetics, underlying order has been suggested by Itten through color harmony studies [2]. Itten implies that Judd and Wyszecki's [3] definition of color harmony as "when two or more colors seen in neighboring areas produce a pleasing effect they are said to produce a color harmony" best meets the needs of scientists, designers and artists. The definition of color harmony implies a strong link to the emotional experience "pleasantness" and furthermore influencing the hedonic value [1]. Characteristics such as complementary or analogous hue, lightness or chroma are known to generate color harmony [4].

Ou, et al. [5] aims to clarify emotions and feelings that are provoked by colors. Color can be scaled through four different color semantics; thus being, warm-cool, heavy-light, active-passive and hard-soft. In respect to color appearance attributes these are described with hue angle and chroma; lightness; color difference; and lightness and chroma respectively. These semantic descriptions of color pairs can be determined by adding the single color scores. However, to evaluate the like-dislike scale of color pairs the addition procedure is not suitable [5].

Jacobsen [1] investigated Kandinsky's color-form hypothesis whereby finding that form-color relationships can be stronger associated with world-knowledge. As red was matched with a triangle and yellow with a circle; universal associations of a warning sign and the sun can be align respectively. This color-form relationship discovered by Jacobsen suggests a strong pattern in respect to cultural correspondence and emotional expression.

2. STUDY SETUP AND METHODOLOGIES: This research aims to advance previous color-form studies [1] to a new realm. Our exploratory study examines color-form relationships for luminous stimuli, whereby exposing participants to chromatic and achromatic light combinations. Extending upon Kandinsky's three primary forms, the selection of geometry has been broadened to include seven forms. Each of these forms consists of a filled and filigree version.

Through the use of form as means of expression, three differing sets of chromatic lighting conditions will be tested. By projecting the various chromatic and achromatic combinations upon a plane and within a space; a gesture of form-color matching will be documented. The study motive lies upon the exploration of correspondence between synaesthetic, aesthetic and hedonic values in respect to color light and form.

14 elements (circle, ovoid, square, rectangle, hexagon, trapeze, and triangle) of filled and filigreed nature are offered to match intuitively with the varying paired luminous stimuli by participants. The tested luminous pairs are of chromatic combinations with seven chromatic stimuli and one achromatic stimulus. These combinations are presented in three different conditions. The first condition presents attention balanced pairs as light patches on a room wall.

These pairs have equal visual attraction value as tested in a previous study by Reisinger, et al. [6]. The second condition also presents pairs as light patches on a room wall, but at equal metric luminance. These pairs, due to their chromaticity are not perceived as equally bright [7]. Thirdly is a lit room condition, whereby chromatic light combinations are projected on opposing walls. These pairs have relative luminances according to the equal attraction value criterion and hence are perceived visually balanced.

In both patch-studies all combinations of chromatic-chromatic light and all combinations of achromatic-chromatic light were judged. At the end of the experiment each participant rated all 14 elements according to intrinsic form preference.

In the room study, participants were exposed to various chromatic-chromatic combinations but judged only their personal favorite. The same room was used for all conditions; however different participants (n=24 to 28) were used between each of the chromatic patch conditions and the chromatic room conditions.

3. EXPERIMENT AND RESULTS:

3.1 Experiment One: The light scenario consists of equidistant colored light spots which are juxtaposed. The light sources used were trichromatic (RGB) LED systems. All together 21 chromatic-chromatic and 7 achromatic-chromatic combinations were shown to participants. Table 1 presents the stimulus characteristics for both patch conditions. The achromatic light used was of a correlated color temperature of 6500K. The 28 settings were randomized and participants were exposed to the stimuli for approximately 45 seconds, positioned at a distance of about 3 meters from the wall.

In experiment one, all stimuli combinations were adjusted to exhibit equal attraction values, as that measured against an achromatic reference by Reisinger, et al. [6]. This condition allows for the stimuli to appear visually balanced to the viewer with equal amounts of attention on each light patch. 1.1cd/m^2 was measured as the average luminance of the surrounding background.

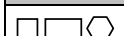
3.2 Experiment Two: In experiment two stimuli were presented at equal luminance. It must be noted that chromatic combinations under equal luminance may appear visually unbalanced as the chromatic light is not perceived equally bright for all hues. The average luminance of the surround background measured 0.8cd/m^2. The experiment procedure was same as in experiment one.

Table 1: Hue angle, luminance and chromaticity coordinates (u', v') of the stimuli used in experiment one and two.

			Experiment One			*Experiment Two*		
Colour	LED	Hue_{uv}	*L*	u'	v'	*L*	u'	v'
Achromatic	R+G+B	0	9.2	0.20	0.47	3.4	0.20	0.47
Blue	B	272	1.7	0.20	0.20	3.4	0.21	0.13
Green	G	143	5.0	0.09	0.55	3.4	0.09	0.55
Red	R	9	3.5	0.43	0.50	3.4	0.46	0.51
Cyan	B+G	188	5.8	0.11	0.46	3.4	0.11	0.46
Yellow	G+R	90	7.4	0.20	0.54	3.4	0.20	0.54
Orange	G+R	23	6.5	0.34	0.53	3.4	.33	0.52
Purple	B+R	323	3.1	0.34	0.36	3.4	0.36	0.34

3.3 Results of Experiment One and Two: Results of Experiment One and Two: From examination of the achromatic-chromatic pairs in the two experiments, a key (Table 2) has been suggested to best scale the hue pairs in accordance to the seven forms. This data and visual representation aims to introduce the proposed color-form relationship for subsequent analysis of the other conditions.

Table 2: The form expression key as derived from achromatic-chromatic combinations.

R	O	Y	G	C	B	P
						
Perpendicular/ Obtuse	*Soft*			*Perpendicular/ Obtuse*		*Acute*

To extend upon this key, three chromatic-chromatic example pairs of both experiment one and two are shown. Within experiment one (Fig. 1), firstly, the yellow-orange combination illustrates that softer shapes such as the circle and ovoid are exceedingly popular. The blue-yellow combination is expressed most commonly through angular shapes such as rectangles, squares and triangles. While the ovoid is a popular form of expression in the blue-purple combination there are no circle selections. However the triangle and rectangle selections are second in popularity. In experiment two (Fig. 2) of equal metric luminance the combination yellow-orange is commonly expressed through the circle and ovoid shapes. The blue-yellow combination presents relatively equal form selections. However, in the blue-purple combination the

triangle followed by the rectangle and square is most common expression.

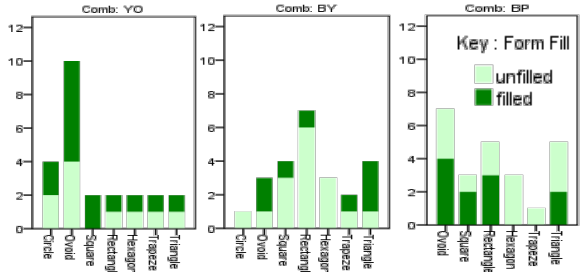


Fig. 1: Three chromatic light combinations of balanced attraction, illustrating the most common form association.

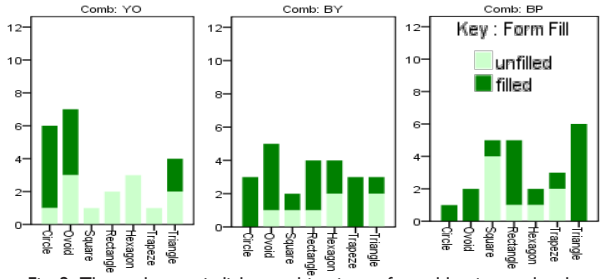


Fig. 2: Three chromatic light combinations of equal luminance levels, illustrating the most common form association.

To facilitate the study of correspondence between chromatic-chromatic combinations and form, the seven forms have been categorized into the three groups (Table 3).

Table 3: Grouping of forms into three categories

Soft Shapes	Perpendicular/ Obtuse Angle Shapes (including 90^0)	Acute Angle Shapes
Circle, Ovoid	Square, Rectangle, Hexagon	Trapeze, Triangle

3.4 Form expression predictions through addition: If additional behavior holds, predictions could be made by applying the derived key. For each color in the light combination, the associated form must be taken. These two forms are added and the overall form expression of the light scenario can be predicted. Table 4 and 5 contains the dominant form expression of the various chromatic-chromatic combinations in addition to the overall form count, in respect to the three description categories concluded.

Table 4: Form selection for experiment one.

Soft/Perpendicular/Acute Count	Prominent Form Selection: R	O	Y	G	C	B	P
R		●	■	▲	▲	■	●
O	13/6/5		●	■	●	■	●
Y	7/12/6	14/6/4		■	●	■	●▲■
G	7/8/10	5/12/7	8/11/5		■	■	▲■
C	4/9/12	10/8/6	12/5/7	8/9/7		▲	▲
B	5/10/9	3/10/11	4/14/6	8/9/7	3/9/11		■
P	13/6/5	12/9/3	8/8/8	4/11/11	6/7/11	7/11/6	

Table 5: Form selection for experiment two.

Soft/Perpendicular/Acute Count	Prominent Form Selection: R	O	Y	G	C	B	P
R		●▲	■	■	■	■	■
O	10/4/10		●	■●	■	■	▲
Y	8/9/7	13/6/5		●	●	■	■
G	6/12/6	9/9/6	13/6/5		■	■	■▲
C	5/10/9	8/10/6	15/5/0	7/14/3		▲	▲
B	5/12/7	4/13/7	8/10/6	5/12/7	8/7/9		■
P	8/12/4	8/6/10	4/11/9	6/9/9	8/4/12	3/12/9	

It is noted combinations containing yellow and orange are commonly expressed by soft shapes. Combinations of purple or red with green or cyan are commonly expressed as acute shapes. In experiment two, soft shapes are chosen for combinations containing orange or yellow. But in general soft shapes are less often chosen in favor of rectangular ones. The color-form association key derived from single colors appears more effective when summarizing the form expression of chromatic light that is balanced. While this key can also be applied to the light combination of equal luminance (Table 5), it appears weaker and more anomalies do occur.

3.5 Preference for shape and fill characteristic: As means of expression, participants had the choice of solid or filigree elements. A form preference testing was done in the first and second experiment independent of the form-color relationship testing and therefore testing the form's intrinsic aesthetic appeal as opposed to a form's color

correspondence. The result shows a bias to round shapes and to filigree elements (Table 6). Both the patch studies and the later described room study confirm such general preference. The apparent trends suggest further exploration of the impact of hedonic motivations.

Table 6: Ranking of form preference, independent of color association.

Form Rank	Form	Rank Fill Elements	Rank Filigree Elements
1	Circle	1	2
2	Ovoid	3	4
3	Square	6	5
4	Hexagon	7	8
5	Triangle	9	11
6	Rectangle	10	12
7	Trapeze	13	14

3.6 Experiment Three: The third experiment presents a room which is lit by 6 spotlights directed to one wall and 5 linear luminaries used as wall washers on the opposing wall. The room under went 28 different light combinations per participant, entailing the colors red, green, blue, yellow, cyan, purple and orange. This includes 21 chromatic light combinations plus a selection of 7 chromatic light combinations with an achromatic luminous object added. The color combination sequence and wall projection was randomized for each participant. The experiment setup requested the participant to choose their seat direction to face the colored wall that exhibited a higher attraction value. From in total 84 combinations offered participants declared their favorite light combination which was also expressed through the selection of a form. This being seven different forms, of both a filled and filigreed nature (n=14).

3.7 Results of Experiment Three: Table 7 presents the personal preference from the 42 basic luminous combinations plus variations with an achromatic luminous object added. The color combination red-orange, for example was chosen three times, featuring an orange patterned wall with a red uniform lit wall, while the reverse arrangement of the same color combination was chosen once. The most popular chromatic light combinations are purple-red, cyan-orange and orange-red. Details about form type choice and the colors they were associated with are given in table 8 (25 of the 28 participants responded to this question).

Table 7: The favored color light combinations for a room.

Spot Color \ Wall Wash Color	R	O	Y	G	C	B	P
R		1	1				1
O	$3^{(1)}$		3		-		-
Y	$2^{(1)}$	-		-	-	-	$1^{(1)}$
G			1		-	-	
C		$5^{(3)}$	$1^{(1)}$	1		-	-
B			$1^{(1)}$	1	$1^{(1)}$		
P	$3^{(2)}$	$1^{(1)}$	-		1		

$^{(n)}$number of cases including an achromatic luminous object

It can be noted that the preferred combinations are expressed by round shapes dominantly. These results are somewhat analogous to that found in experiment one and two.

Table 8: Table presenting the frequency of form types in relation to chromatic light

○	⬭	□	▭	⬡	⏢	△
5	13	-	4	2	-	1
18		6			1	
Red ● 7 Orange ● 7 Yellow ● 8 Green ● 3 Cyan ● 5 Blue ● 3 Purple ● 3		Red ● 3 Orange ● 5 Yellow ● 1 Cyan ● 2 Purple ● 1			Yellow ● 1 Purple ● 1	

4. DISCUSSION: As can be seen from the results, a faint relationship between chromatic light and form can be depicted. Yellow and orange light are more commonly expressed through the soft forms, such as an ovoid or circle. While purple chromatic light are increasingly often expressed with triangles. This relationship is conflicting of Kandinsky's [1] color-form assignment and correspondence theory; which suggests that yellow matches a triangle, blue matches a circle and red matches a square. Jacobsen [1] however suggests that color-form assignments are influenced by cultural factors. Therefore through world knowledge or universal symbols, color-form association can be determined such as yellow circle equally the sun or a red triangle equally a warning sign. Jacobsen [1] agrees that cultural associations to color-form have the potential to vary and can sometime be ambiguous, which is apparent in this testing. For this particular study the ambiguity of the color-form association may also be due to

the stimuli being of a luminance nature and heterogeneity of the tested group.

By reducing the color-form relationship to color and form preference respectively, further insights can be drawn. In relation to color preference of two chromatic light pairs, it is known that a high preference is expressed for yellow when combined with orange, green and cyan for both condition of equal luminance value and equal attraction value [6]. As for form preference the softer and more organic shapes such as the circle and ovoid are also preferred, over the more angular shapes. Furthermore, the dominant use of round shapes in evaluating favorite combinations indicates also matching according to hedonic value.

While filigreed shapes are preferred, within the balanced attraction value combinations and the equal metric luminance combinations form expression differences do occur. Not included in the analysis but should be mention is the attraction balanced combinations purple–orange, red-orange and red-purple are expressed heavily through filled shapes. This differences can probably be related to the chromatic pair's deemed weight as these combinations are listed highly in the heaviest chromatic pairs of balanced attraction [6]. As for the equal luminance value the combinations blue-purple, blue-red and purple-red are expressed heavily through filled shapes. These three combinations are listed highly within the warmest color combinations of equal luminance value [6].

The chromatic combinations illuminating a room can also loosely be aligned with the color-form key devised. These favored combinations were predominately expressed through softer forms such as ovoid and circles.

To more deeply explore potential color-form association and its dependencies it seems to be required to devise a more homogeneous group (i.e. designers) and testing a larger group.

5. CONCLUSION: It can be concluded that a universal correspondence for color and form is a tempting idea, but cannot be supported by evidences of correspondence of chromatic light stimuli and form. From the obtained results no simple equation can be extracted to describe the relation between character of a chromatic light combination and the expressed character of a geometric element. For light stimuli there is no synaesthetic match evident as changing intensities of the constituents changed associated form match.

What was found is a vague alignment of form to specific colors e.g. yellow and orange to round shapes. Predictions for form associated with color combinations on basis of additive behavior demonstrated weak, yet slightly better for the attention balanced stimuli set than for the set with equal metric luminance.

Throughout the different levels of complexity of presenting the chromatic light combinations consistency for form correspondence is barely evident. The most certain and consistent link between the chromatic light combinations and the characterization by form seems their perceived pleasure. Round shapes and yellow, orange colors rate therein high and match. The attempt to deconstruct an aesthetic experience by scientific examination did not succeed. The most likely reasons evident for a person to chose was out of hedonic motivation. This could be traced throughout all three experiments. In terms of understanding between arts and science the experiments articulated intrinsic limits hampering generalization that can be discussed further.

6. REFERENCES:

[1] Jacobsen, T. (2002), 'Kandinsky's questionnaire revisited: fundamental correspondence of basic colors and forms', Percpetual and Motor Skills, (Vol. 95): 903-913.

[2] Itten, J. (1967), 'The art of color: the subjective experience and objective rationale of color'. Germany, John Wiley and Sons.

[3] Judd, D., Wyszecki, G. (1975), 'Color in business, science and industry'. 3rd ed. New York: John Wiley and Sons.

[4] Westland, S., Laycock, K., Cheung, V., Henry, P. and Mahyar, F. 2007. 'Colour Harmony'. Colour: Design & Creativity 1(1):1-15.

[5] Ou, L. C., Luo, M.R., Woodcock, A. and Wright, A. 2004. 'A study of colour emotion and colour preference. Part I: Colour emotions for single colours'. Colour Research and Application 29 (3): 232-240.

[6] Reisinger, M., Huedo, A., Vogels, I. and Heynderickx I. 'Preference for two color chromatic light pairs and their characterization by semantic scales'. In Proceedings of the 11th Congress of the International Colour Association (AIC 2009) Sydney.

[7] Nayatani, Y. and Sakai, H. (2007). 'A tentative proposal for integrated photometric system and its application to luminous colors'. Color Research and Application 32(6): 440-448.