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The Hue of Angles — Was Kandinsky Right?

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Abstract

This article presents an experimental study on the natural association between angles and colour. Specifically, for each angle width — formed by two segments joined at their vertex — studied, participants were asked to indicate the colour that they perceived as most closely related to it, choosing from the NCS Hue Circle. The results show that participants systematically established a natural and consistent association between certain angles and colours, when explicitly asked to choose the colour that they perceived as most naturally related to a given angle presented as two lines. The overall results suggest an association between acute angles and warm colours and obtuse angles and cool colours, confirming Kandinsky's hypothesis. In particular, the strongest relations were found between the angle of 22.5° and yellows, the angles of 45°, 90° and 135° and green-yellows, and the angle of 157.5° and red-blues, when angles were presented on a white background.

Keywords

Colour, Kandinsky, natural associations, visual shape

1. Introduction

Recent studies have shown the existence of natural cross-modal associations (between different sensory modalities) and cross-dimensional associations (between different dimensions of the same sense modality) not only in synaesthetes but also in the general population (see Spence, 2011 for a review). As regards colour, cross-modal associations have been found, for example, between odours and colours (e.g., Demattè *et al.*, 2006), between tastes/flavours and colours (see Spence *et al.*, 2010 for a review), between sounds/music and colours (e.g., Palmer *et al.*, 2013; Ward *et al.*, 2006), and between tactile sensa-

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tions and colours (Ludwig and Simner, 2013). Examples of cross-dimensional associations in the case of colour are those between graphemes and colours (Jürgens and Nikolić, 2012; Lau *et al.*, 2011; Simner *et al.*, 2005; Spector and Maurer, 2008, 2011) and shapes and colours (Albertazzi *et al.*, 2013; Dadam *et al.*, 2012).

On examining the relationship between shape and colour, these latter studies have demonstrated the existence of natural associations between particular shapes and characteristics of colour like hue and temperature (Da Pos and Valenti, 2007). The results are systematic: it has been found that certain shapes are more frequently related to cool colours, such as greens and blues, while others are so with warm colours like reds and yellows. In particular, a study on natural shapes (Dadam *et al.*, 2012) has shown that round shapes are matched mainly by reddish colours in the yellow–red interval of the NCS Hue Circle; and that elongated shapes are matched mainly by greenish and bluish colours in the blue–green interval of the NCS Hue Circle. Likewise, a study on geometric shapes (Albertazzi *et al.*, 2013) gave evidence for systematic associations between particular figures and hues: for example, between a circle or a square and reds, a triangle or a pyramid and yellows, a hexagon and red-blues, and a parallelogram and blues. Also these results suggest a role of the temperature of colour in the association of particular colours with particular shapes, as well as a role of the natural lightness of hues: the circle and the triangle were the 'warmest' shapes, whereas the parallelogram was the 'coolest' and the square and the circle were the 'darkest', as opposed to the pyramid and the cone, which were the 'lightest' shapes within the set of shapes studied.

These results also allow some predictions to be made: for instance, one would expect to find a correlation not only between colour and type of shape but also between colour and the parts of a shape, in regard to both the relative extension of the parts involved and the overall characterization of the whole. However, because this concerns perceptual shapes, it does not follow that the colour of the whole is given by the sum of the colours of the various individual parts.

These studies have a correlate in the analyses conducted by Kandinsky in the artistic field, the findings of which our results have partly confirmed and partly refuted: for example, in the general population, the associations between squares and red and between triangles and yellow have been confirmed, while circles are not associated with blue (Albertazzi *et al.*, 2013). Kandinsky's shape/colour analysis was part of his broader investigation into the elements of pictorial space in terms of points, lines, and surfaces (Kandinsky, 1947) and their cross-modal characteristics. Moreover, Kandinsky considered an acute angle to be warm and tending to yellow, and an obtuse angle to be cool and tending to blue.

In the research reported here we wanted first to determine whether there is a natural association among angles formed by two lines, hue and temperature of colour. In particular, the intention was to verify whether two segments joined at their vertex, and forming an angle, are perceived with different hues. Our second objective was to conduct comparisons with the results previously obtained in order to determine whether lines forming angles are decisive for the natural association between geometric figures and colours: for example, whether the presence of lines forming acute angles in a triangle or of lines forming right angles in a square influence the association of the overall figure with a particular hue/group of hues; and therefore whether the current results could explain those previously obtained. With respect to the experimental design previously adopted, apart from the diversity of the stimuli, the intention was also to test for a possible influence of the colour of the background in the associations.

2. Method

2.1. Participants

Fifty-six participants volunteered for the Experiment: 32 women and 24 men (mean age = 22.03, SD = 3.72; range: 19–44 years). All participants were recruited from students at the Department of Psychology and Cognitive Science, University of Trento, Italy. The only exclusion criterion was self-reported defective colour vision. A preliminary phase was performed, where each subject was asked to identify unique hues, the purpose being to detect visual defects (such as Daltonism or large deviations in the choice of unique hue) that were not self-reported. No subject declared a conscious synaesthesia.

2.2. Materials

The materials consisted of a Hue Circle and a series of angles formed by two segments joined at their vertex. The Hue Circle, taken from the Natural Color System Atlas (http://www.ncscolour.co.uk/information/ncs_system.html), presents 40 hues, including the four unique hues — yellow, red, green, and blue — and the intermediate ones (see Supplementary Fig. S1 online). The independent variable was the kind of lines presented, a categorical variable with six levels. The dependent variable was the colour chosen. The Hue Circle had a diameter of 375 mm and was made up of 40 small circular patches of 18 mm.

Lines forming angles of different widths (22.5°, 45°, 90°, 135°, 157.5°, 180°) were displayed one at a time with their vertex centered with respect to the Hue Circle. The angles were presented in achromatic grey (RGB = 125, 125, 125) and reproducing only their sides (length = 97 mm; thickness = 3 mm). On every presentation the orientation of the Hue Circle varied at random (i.e., the colour to the north of the screen was not always the same). Between one presentation and the next, the angles of each width were presented in random orientation in each of the eight possible orientations (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°), for a total of 48 presentations. The same stimuli were presented first in the version with a white background and then in the version with a black background, or *vice versa*. In the course of the experiment, therefore, each subject saw a total of 96 stimuli (six angles × eight orientations × two backgrounds).

2.3. Task and Procedure

The experiment was conducted in a dimly lit laboratory (1 lux on the walls). The stimuli consisted of the series of angles and the Hue Circle described above. Participants were seated at a work desk at a distance of about 60 cm from the screen, in front of which was positioned a black cylinder which functioned as a reducer and isolator of light from the room. The cylinder had a diameter of 280 mm and was around 500 mm long (equal to the distance of the subject from the monitor). On looking through the cylinder, the subject saw the central part of the monitor in which the stimuli and the hue circle appeared. This procedure ensured that, during observation of the stimuli, the light originated from the monitor and not from reflections on the screen.

The stimuli were centred on the screen of a CRT 19-inch ViewSonic G90fB Graphics Series, 1024 × 768 resolution, controlled by a DELL Optiplex GX270 computer, on a white background: 92 cd/m^2, $L^* = 94.65$, $a^* = 4.49$, $b^* = 0.2$, $x = 0.3044$, $y = 0.3194$. Each stimulus was made to appear at the centre of the screen and concentric with the circle. To perform the task, the subjects were required to use only the keyboard and the mouse.

First a questionnaire was administered to the participants with questions relative to their experience of colour, possible colour blindness (including Daltonism), and synaesthesia. Moreover, to check for the existence of colour-related visual defects that were not self-reported, the participants performed a preliminary task that required them to identify their subjective unique hues on the NCS Hue Circle. The interface asked each participants to select, upon the appearance in random orientation of the Hue Circle, the hue that she/he perceived as corresponding most closely to ‘red without shades of blue or yellow’; to ‘yellow without shades of red or green’; to ‘green without shades of yellow or blue’; and to ‘blue without shades of green and red’.

The angle/colour matching task consisted of two experimental blocks, carried out in sequence, in which the same stimulus figures were presented, first against a white background and then against a black background, or *vice versa*.

Proposed for each experimental block were 48 presentations of the circle of colours with different orientations. Shown internally to the circle were the lines forming angles of each width in their various orientations. The task of the participant was to colour the lines, to see whether the given colour was perceptually congruent with the angle width, choosing it from among the 40 hues of the Hue Circle. By clicking on a colour, the subject could view the lines, which were originally grey, in the colour selected. S/he could then confirm his/her choice by clicking on the coloured lines and move to the next presentation; or s/he could make further attempts until s/he was satisfied with the lines/colour association made. An example of colour choice is shown in Supplementary Fig. S2.

The participants were given the following written instructions for the angle/colour matching task:

> *At the centre of the screen you will see, one at a time, a series of 'angles' (figures formed by two intersecting lines) with different orientations. On the basis SOLELY of the impression produced by the width of the angle, colour the two lines that form the angle with the colour that you perceive as most closely matched with it. Take care NOT TO FAVOUR the colour or colours of the Hue Circle close to the edges of the figure in each presentation.*
>
> *You should not make associations between angle and colour on the basis of past experience. To perform the task, click on the colour that you associate with the angle. You can repeat your choice until you are satisfied with the result. When you are satisfied, click on the vertex of the coloured angle to confirm your choice definitively and go on to the next test. N.B.: once you have confirmed your choice, you cannot go back on it. Press the SPACE BAR to proceed.*

In Supplementary Fig. S3 are shown the lines forming angles with the six widths studied (22.5°, 45°, 90°, 135°, 157.5°, 180°), in one of the eight orientations in which they could appear during the experiment with the white background. Note that the circle of colours rotated at random between one presentation and the next.

This task was followed by the second experimental block, in which the subject was asked to perform the same angle/colour association task, the only variant being that the background was now black rather than white.

3. Statistical Methods

The chi-square test for a contingency table was used to evaluate the departure from independence hypothesis. A residual analysis was performed to identify those cells of the contingency table where the departure from the independence hypothesis was most evident. Analyses were performed with R 2.15.0 software (R Development Core Team, 2011).

4. Results

The chi-square test was used to evaluate the departure from independence with respect to the association between the variables ‘angle’ and ‘colour’ separately for the white and the black background. A significant association was found between these two variables both when the background was white (chi-square = 317.5; DF = 195; $p < 0.001$) and when the background was black (chi-square = 286.4; DF = 195; $p < 0.001$).

4.1. White Background

When the background was white, there were 31 residuals greater than 1.96 in absolute value (12, i.e., 5% of the total, were expected if colour was randomly selected). A positive residual means that the selected angle ‘attracts’ the corresponding colour; a negative residual means that the selected angle ‘repels’ the corresponding colour.

As regards the acute angles, the highest positive residual (4.99) for 22.5° was associated with Y and the highest negative residual (−2.77) was associated with B70G; the highest positive residual (3.50) for 45° was associated with G40Y and the highest negative residual (−2.11) was associated with R90B. As regards the obtuse angles, the highest positive residual (2.26) for 135° was associated with G20Y and the highest negative residual (−2.05) was associated with R; the highest positive residual (2.06) for 157.5° was associated with R80B and the highest negative residual (−2.29) was associated with G40Y. In Fig. 1 the residuals greater than 1.96 (in absolute value) for acute and obtuse angles are shown (in Supplementary Fig. S4 the same figure is shown with the barplot of the residuals coloured with the same colours of the Hue Circle, shown in Supplementary Fig. S5 with the corresponding colour code).

Inspecting Fig. 1, a pattern of residuals emerged. On considering the two acute angles, positive associations were found mainly with red and yellow colours and negative associations with blue and green ones. The opposite was the case when the two obtuse angles were taken into account. These results are more evident if we consider the number of attractions and repulsions in Fig. 1 after having divided the Hue Circle into two halves. The first half, starting with G50Y and ending with R40B, can be considered the ‘warm’ half of the Hue Circle. The second, starting with R50B and ending with G40Y, can be considered the ‘cool’ half of the Hue Circle. The acute angles mainly attract a ‘warm’ colour (5 out of 6), while they always repel a ‘cool’ colour (3 out of 3). The reverse occurs when the obtuse angles are taken into account. They always attract a ‘cool’ colour (6 out of 6) and mainly repel a ‘warm’ one (3 out of 4).

As far as the 90° angle is concerned, the two highest positive residuals were associated with G30Y (3.21) and with Y20R (2.58), while the highest

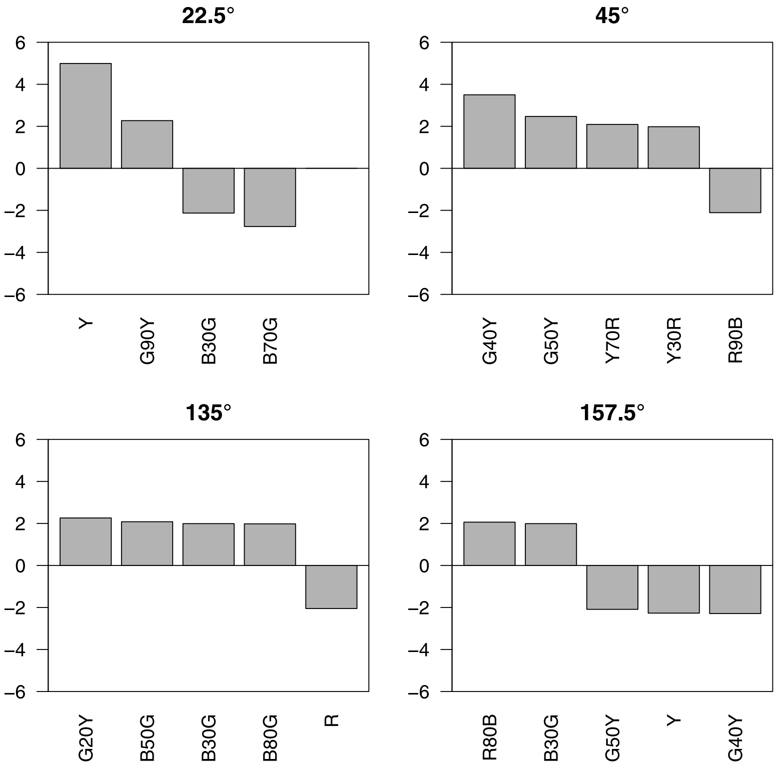

Figure 1. 'Attractions' and 'repulsions' between the 40 colours of the Hue Circle and four selected angles when the background was white. The heights of the bars correspond to the standardized residuals higher than 1.96 (in absolute value). An upward bar indicates an attraction; a downward bar indicates a repulsion.

negative residual (−1.98) was associated with B40G. The highest positive residual (3.68) for 180° was associated with G and the highest negative residual (−2.88) was associated with G30Y.

4.2. *Black Background*

When the background was black, there were 19 residuals greater than 1.96 in absolute value (12 were expected if colour was randomly selected); on the other hand, there were 10 residuals greater than 2.57 in absolute value (2.4, i.e., 1% of the total, were expected if colour was randomly selected).

As regards the acute angles, the highest positive residual (3.46) for 22.5° was associated with G90Y and the highest negative residual (−2.60) was associated with G30Y; the highest positive residual for 45° was 1.95 and was associated with Y40R, while the highest negative residual (−2.41) was associated with G. As regards the obtuse angles, the highest positive residual (2.78) for 135° was associated with B30G and the highest negative residual (−3.78)

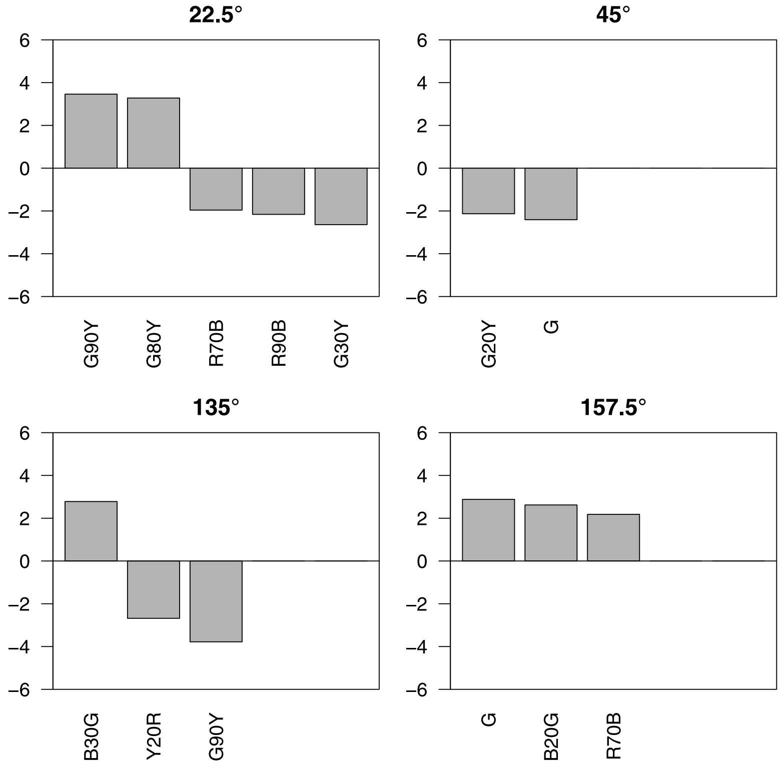

Figure 2. 'Attractions' and 'repulsions' between the 40 colours of the Hue Circle and four selected angles when the background was black. The heights of the bars correspond to the standardized residuals higher than 1.96 (in absolute value). An upward bar indicates an attraction; a downward bar indicates a repulsion.

was associated with G90Y; the highest positive residual (2.88) for 157.5° was associated with G while the highest negative residual (−1.81) was higher than −1.96. Figure 2 shows the residuals greater than 1.96 (in absolute value) for acute and obtuse angles (again, the same figure is shown with the barplot of the residuals coloured with the same colour of the Hue Circle in Supplementary Fig. S6).

Figure 2 resembles the pattern of residuals observed in Fig. 1. The acute angles always attract a 'warm' colour (2 out of 2), while they always repel a 'cool' colour (5 out of 5). The reverse occurs when the obtuse angles are taken into account. They always attract a 'cool' colour (4 out of 4) and repel a 'warm' colour (2 out of 2).

As far as the 90° angle is concerned, the two highest positive residual were associated with G30Y (3.37) and with R30B (2.50), while the highest negative residual (−2.42) was associated with B80G. The highest positive residual

(2.86) for 180° was associated with B80G and the highest negative residual (−1.80) was higher than −1.96.

5. Discussion

In the experiment described, the existence of a natural association between specific geometric angles formed by two lines and specific hues in the general population was tested. In previous studies we hypothesized that there may be some kind of intermediate visual structure which explains the particular combinations or connections that we found between shape and colour: such a structure might have been the angle. One would thus have examined whether angles of different amplitude are viewed as naturally associated with specific hues and whether this result would confirm and explain the associations previously found between shapes and hues. As said, the only variation with respect to the experimental design in Albertazzi *et al.* (2013), besides the different stimuli, consisted in presenting the figures against both a white and a black background.

To this end, we used a selection of basic geometric angles to evaluate whether different amplitudes indeed give rise to consistent choices of hues valid for participants who, although independent, shared the same culture, age, education, and so forth. We expected a non-random distribution of frequency of choice of hues for the different angles presented. Our results confirm previous findings (Albertazzi *et al.*, 2013; Dadam *et al.*, 2012; Spector and Maurer, 2008, 2011) of the existence of natural associations in the general population — for example, those between different perceptual features in the same or different modalities — and they further extend the range of the associations of colours to angles of different amplitude. As regards the other specific aspects of colours examined here, the results suggest relations between angles and some colour qualities like their temperature (warm/cool). Acute angles are mainly associated with warm colours, while obtuse angles are mainly associated with cool colours. This finding is particularly evident when considering the strongest attraction for acute (which is Y, i.e., a warm colour, for the 22.5° angle) and obtuse angles (which is G, i.e., a cool colour, for the 157.5° angle).

Kandinsky's (1947) hypotheses on the colour of angles — the right angle as cool/warm, the acute angle as warm and tending to yellow, the obtuse angle as cool and tending to blue — are partly confirmed by our results. In our study, acute angles also appear to be warm, and obtuse angles appear to be cold. Specifically, on the white screen the 22.5° angle is Y, the 45° one is G40Y, the 135° one is G20Y, and the 157.5° one is R80B. On the black screen, the 22.5° angle is G90Y, the 45° one is Y40R, the 135° one is B30G, and the 157.5° one is G. The strongest attraction for the 90° angle was with G30Y for both the black and the white background, but not with Red–Violet as hypothesised by Kandinsky. However, the second attraction for the angle of 90° with the black background is R30B, and therefore with Kandinsky's 'violet'. Not so with the white background, where the second attraction is with Y20R, and therefore not with violet. We may therefore say that with the black background Kandinsky's hypothesis is not confuted. Overall, our results are consistent when considering both the background and the opposition between attractions and repulsions. A different consideration applies to the 180° angle, which is not seen as an angle but as a line.

In light of our previous studies on the matching between geometric shapes and colour (Albertazzi *et al.*, 2013) the association of the triangle with yellow could be explained by the fact that it is characterized by acute angles, here associated primarily with yellows. But not in all cases is a direct correspondence found between the colour of a figure as a whole and the colour of its parts (e.g., angles), which again demonstrates that the whole is not equivalent to the sum of its parts. In regard to the study of the primitives of a shape and their association with colour, further experiments could be conducted to analyse whether angles drawn not with two lines but with a coloured surface, and which therefore have a perceptively different appearance, may result in different associations (i.e., between parts of surfaces and colour) and more consistent with those found for plane figures. Other experiments could verify the role of the angles in the colour of zigzag lines drawn with different slants. Moreover, the shape/colour association was not verified symmetrically, and further experiments should check whether the same results can be achieved by associating an angle with a given hue/s. Finally, it would be interesting to repeat the experiment in other contexts and with different people. For that matter, a recent experiment conducted in Japan (Chen *et al.*, 2013), which used the design of our previous research on the association between shapes and colours (Albertazzi *et al.*, 2013), has obtained similar results.

The purpose and the results of this research once again emphasize that the perception of colour and shape can be analysed according to a specific methodology, without necessarily drawing on the physics or physiology of colour. From a systematic point of view, on the basis of the results obtained we may also assume that the association between colour and form is intrinsic to the meaning of a shape in qualitative perception [Kandinsky (1912) called this relationship 'inevitable']: the choice of a colour to combine with a shape, in fact, was made by our participants merely according to an association perceived as natural. In the present case of angles, a top-down association was less likely than that which can be supposed between shapes and colours (such as, for example, the association between a circle and the colour red). The effect therefore seems be due to the presence of a generalized synaesthesia in the normal population as a pattern of properties perceived as intrinsically connected (Albertazzi, 2013) more than to a synaesthesia induced top-down or ideasthesia (Myles *et al.*, 2003; Nikolić, 2009). Nevertheless, this hypothesis should be verified with appropriate experiments.

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