Color for the perceptual organization of the pictorial plane: Victor Vasarely's legacy to Gestalt psychology

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ABSTRACT

Victor Vasarely's (1906–1997) important legacy to the study of human perception is brought to the forefront and discussed. A large part of his impressive work conveys the appearance of striking three-dimensional shapes and structures in a large-scale pictorial plane. Current perception science explains such effects by invoking brain mechanisms for the processing of monocular (2D) depth cues. Here in this study, we illustrate and explain local effects of 2D color and contrast cues on the perceptual organization in terms of figure-ground assignments, i.e. which local surfaces are likely to be seen as “nearer” or “bigger” in the image plane. Paired configurations are embedded in a larger, structurally ambivalent pictorial context inspired by some of Vasarely's creations. The figure-ground effects these configurations produce reveal a significant correlation between perceptual solutions for “nearer” and “bigger” when other geometric depth cues are missing. In consistency with previous findings on similar, albeit simpler visual displays, a specific color may compete with luminance contrast to resolve the planar ambiguity of a complex pattern context at a critical point in the hierarchical resolution of figure-ground uncertainty. The potential role of color temperature in this process is brought forward here. Vasarely intuitively understood and successfully exploited the subtle context effects accounted for in this paper, well before empirical investigation had set out to study and explain them in terms of information processing by the visual brain.

"Every form is a base for color, every color is the attribute of a form"

Victor Vasarely (1906–1997)

1. Introduction

Victor Vasarely's (1906–1997) major work was essentially inspired by Gestalt Theory (Metzger, 1930; Rubin, 1921; Wertheimer, 1923). It exploits axonometric squares or cubes with more or less curvilinear contours, to convey the appearance of a three-dimensional structure to the pictorial plane. By varying the size, luminance contrast, and/or color of the cubes, Vasarely created powerful 3D effects using minimalist variations in 2D geometry. Perception science has only recently begun to understand the brain mechanisms driving this perceptual organization of planar image data on the basis of monocular cues to 3D that were already described by Leonardo da Vinci (da Vinci, 1651), and further discussed and illustrated centuries later by the Italian Gestalt Theorist Gaetano Kanizsa (e.g. Kanizsa, 1979). Such 2D cues enable both grouping and/or segregation of specific parts of the image plane on the basis of local differences in size, luminance contrast, and/or color and thereby confer order to a multitude of simultaneously incoming visual signals (von der Heydt, 2015). Such order expresses itself in statistically significant brain representations of structural regularity with psychophysically measurable perceptual correlates (Dresp-Langley et al., 2017).

Two of the most powerful 2D cues to visual 3D are relative size and linear perspective (Figure 1). Of two objects in the pictorial plane, the larger one is statistically the more likely to appear nearer to the human observer than the smaller one, as shown psychophysically in systematic studies on human perception (Guibal and Dresp, 2004). This monocular depth cue of relative size is perceptually reinforced by additional 2D cues of linear perspective (Figure 1A) and/or luminance contrast (Figure 1B), where the object with the lower position in the plane and/or the stronger contrast will have an even higher probability to appear nearer to the human observer, especially in increasingly complex pictorial pattern contexts, where a single local cue of relative size becomes increasingly harder to detect if not supported by an additional depth cue (Dresp at al., 2017).
Curvature (Dresp-Langley, 2015a, b) and bilateral symmetry (Dresp-Langley, 2016) reinforce the effects of linear perspective on 3D shape perception in the pictorial plane (Dresp-Langley, 2019). Vasarely combined these geometric 2D cues, which produce particularly salient depth effects in displays with achromatic contrast variations. Two examples, “Bianco” (1987) and “Vega III” (1956) are shown here (Figure 1A and B, respectively).

Other, more complex, geometric cues enabling the perception of 3D structure in pictorial displays are contour intersection and partial surface occlusion. They allow for the emergence of surfaces that convey sensations of “nearer” versus “further away” (Kanizsa, 1979; Grossberg, 1994, 1997) that can be psychophysically measured in terms of the probability of the vertical surface (Figure 2A, B, C) to appear “nearer” to a human observer (Dresp et al., 2002; Guibal and Dresp, 2004). Line contours and adjacent groups of lines giving rise to the emergence of surfaces in the pictorial plane. In the case of spatially superposed (A, B, C) or spatially adjacent groups of lines giving rise to the emergence of surfaces in the pictorial plane. In the case of spatially superposed (A, B, C) or spatially adjacent (D, E) line contours, 2D cues of local contour intersection (A, B) and/or partial surface occlusion determine, as shown in psychophysical studies, which surface is the most likely to appear nearer to the human observer. A strictly local cue of contour intersection (A) is perceptually reinforced by additional cues of surface contrast and/or partial surface occlusion (B, C). Spatially adjacent rows of orthogonal (D) or phase-shifted lines (E) generate powerful cues of intersection and partial occlusion that give rise to the emergence of perceptual 3D structure, as in Vasarely’s oeuvre “Riu Kiu” (1956) shown here (Figure 2F).

Insights from perception science have led to an understanding that any of the monocular (2D) cues to spatial structure in the pictorial plane may cooperate or compete in the genesis of “nearer”, depending on the way they are combined in a complex image context. This subtle interplay, from cue cooperation to cue competition, in visual perceptual organization is accounted for by the LAMINART models, developed by the mathematician and philosopher Stephen Grossberg and his coworkers (Grossberg, 1994, 1997, 2015), on the basis of cooperative and competitive neural interactions in the visual brain, some of which were found to extend well beyond the previously assumed limits of spatial integration (for a review see Spillmann et al., 2015). It was also found that luminance contrast and color (hue) have a particular status in these interactions. For example, a sufficiently strong local contrast cue competes with, and may override cues of relative size, local contour intersection, and partial occlusion in the perceptual genesis of “nearer” in a given image context (Guibal and Dresp, 2004). The least well studied cue to depth in the pictorial plane is color. A perceptual study by the Japanese physicist Hiroyuki Egusa (1983) has shown that, when no other monocular cues to depth are presented in the image plane, the color (hue) red will determine the object seen as nearer to the human observer when presented together with an achromatic object of the same contrast, shape, and size. Subsequently, it was shown that a fully saturated red may override, or win against, a green with the same luminance contrast, or a grey with a stronger luminance contrast within a restricted range of background grey levels (Guibal and Dresp, 2004). These findings suggest that, when no other 2D cues to depth are given in the plane, color, in the same way as luminance contrast (O’Shea, 1994), acquires the status of a self-sufficient monocular depth cue. This was not known to Vasarely when he created the “Army” (shadow) series in the years 1966–1968. Yet, his intuition and experimentation with color combinations in the plane led him to understand this important, hitherto underrated and not investigated,
function of color in the perceptual organization of complex pictorial patterns. The striking depth effects he obtained are shown here (Figure 3A and B respectively) on the examples of “Army1” (1968) and that of an untitled poster design he created in 1969 for the Thomas Gallery in Munich, Germany.

Hypotheses about how the visual brain generates these color and contrast driven 3D perceptions have been proposed in terms of non-linear antagonistic neural mechanisms, operating simultaneously to produce what is called subjective brightness assimilation and dissimilation effects (Hamada, 1985; Heinemann, 1955; Dresp et al., 1996; Grossberg, 1994, 1997, 2015). Such effects are reflected by perceptions where the subjective brightness of an image background changes in a positive (“brighter”) or negative (“darker”) direction. Depending on the contrast polarity (negative or positive) produced by a pattern placed on the background, the induced change in perceived background brightness is termed “assimilation” when a darker pattern induces perception of a subjectively darker background and a brighter pattern induces perception of a brighter background (Dresp and Grossberg, 1999; Dresp and Langley, 2005; Dresp et al., 1990; Spillmann and Dresp, 1995; Tzvetanov and Dresp, 2002). “Dissimilation” or subjective contrast occurs when a darker pattern induces perception of a subjectively brighter background and a brighter pattern induces perception of a subjectively darker background (Devinck et al., 2006; DeWeert and Spillmann, 1995; Dresp, 1992, 1997; Dresp and Fischer, 2001; Dresp-Langley and Reeves, 2012, 2014a, b, 2018; Dresp-Langley and Grossberg, 2016; Pinna and Reeves, 2006). Results from psychophysical experiments measuring the perception of “nearer” in local shapes embedded in complex pattern contexts have allowed to point towards a functional role of these mechanisms, suggesting that they enable the coherent perceptual organization of the image plane when meaningful physical variations generating geometric depth cues are missing from the image (Dresp-Langley and Reeves, 2014a, b, 2015).

Here, we pursue this further by presenting results from a study where the probability of perceiving a central figural element (a red or a blue square, as shown in Figure 4) with a specific color and luminance contrast as “nearer” or as “bigger” in a pair, and as “nearest” or “biggest” in the whole, complex and variable image context. Pairs of configurations considered for assessing probabilities for “nearer” and “bigger” were L-J, K-G, I-H, F-C, E-B, and D-A, as indicated here above (Figure 1). These were paired in such a way that each pair had the same central local target color in the center of the color-surround configurations is the most likely to be seen as “nearer” and/or “bigger”, which as “nearest” and/or “biggest” in the context of variations given. Presuming that contrast and color are, as predicted, self-sufficient cues to perceptual organization, the results should display intrinsically coherent probability distributions for “nearer” and “nearest” as a function of sensation magnitudes elicited by the colors in the different contexts. Whether subjective depth effects coincide with perceived differences in relative size, where one element appears subjectively “bigger” than the other in a pair, is not known but tested here. A color effect in terms of a functional advantage of the color red is expected in the light of previous findings on
2. Results

The cumulated responses reflecting independent observations relative to “nearer” and “bigger” of two in a pair, and/or relative to “nearest” and “biggest” in a whole image, from the ten independent observers were computed. With eight permutations of paired configurations in image displays presented in the “black wall” and “white wall” conditions, we have a total of $10 \times 8 \times 2$ independent observations.

2.1. Descriptive analyses

In a first analysis, the cumulated responses for “nearer” and “bigger of two in a pair” were sorted in increasing order of magnitude, without looking at which configurations produced them, and plotted as a function of the “black wall” and “white wall” presentation conditions. The results

Figure 3. The functional role of color as a monocular cue to depth has only recently received attention from perception scientists. Vasarely’s combination of variations in color and luminance contrast reveal his deep understanding of the function of color in the perceptual organization of the plane, to which he conveyed compelling effects of 3D structure that are fully appreciated when looking at the original (large scale) versions. Shown here above, in mini format for illustration: In A, the example of “Arny1” (1968), where no monocular cues to depth other than color and contrast are exploited to produce the compelling perceptual 3D structure. In B, that of an untitled poster design he created in 1969 for the Thomas Gallery in Munich, Germany (The Vasarely Foundation, 2020), where depth cues of color and contrast are supported by the variations in relative size of the local shapes. Reproductions shown here were generated from photographs taken by the first author, with permission, at the Vasarely Foundation in Aix-en-Provence, France (The Vasarely Foundation, 2020).

Figure 4. Images produced by the authors for psychophysical investigation. Local shapes were embedded in a complex pattern context, displayed against a “black wall” suggested in the pictorial plane (left), and against a “white wall” (right). Meaningful physical variations generating geometric depth cues (relative size, contour interposition, partial surface occlusion) are missing from these configurations. Local cues of color and contrast enable a coherent perceptual organization of the image plane in terms of which of two surfaces at the center of a paired configuration, numbered here from $L + J$ to $D + A$, is likely to appear nearer to an observer. The corresponding color parameters (RGB, Hue $^\circ$, Luminance (cd/m²), Saturation%), and X, Y, Z color coordinates) are provided in the supplementary Table S3.

Figure 5. Cumulated responses for “bigger” and “nearer”, produced by the twelve paired color-surround configurations (Figure 1) in independent observations, sorted here in the order of ascending response magnitudes for “bigger” associated with the corresponding magnitude for “nearer” elicited by the same display. Results from the “black wall” (top) and the “white wall” (bottom) presentation conditions are shown. A statistically significant correlation (Pearson) between the magnitudes of the responses for “nearer” and “bigger” is found.
from this analysis are shown here below in Figure 5. The observed correlation between cumulated magnitudes for “nearer” and cumulated magnitudes for “bigger” in either (“black wall” and “dark wall”) presentation conditions is statistically significant, as shown by the Pearson correlation coefficients (Pearson’s product moment $P$) computed on the results from the two presentation conditions, with $P = 0.98$ ($p < .001$) for the correlation between “bigger” and “nearer” in the “black wall” condition, and $P = 0.99$ ($p < .001$) for the correlation between “bigger” and “nearer” in the “white wall” condition.

In the next analysis, the cumulated responses for “nearer” and “bigger” of two in a pair” were sorted as a function of the luminance contrast. The latter is the Weber contrast $C = (L_{center}-L_{surround})/L_{surround}$, where $L$ stands for the photometrically determined luminance. The corresponding values in cd/m$^2$ are given in the supplementary Table S3. The Weber contrasts are shown in the text here below in Table 2 of the Materials and Methods’ section for the paired configurations which produced them. Responses were plotted as a function of the Weber contrasts for the “black wall” and “white wall” presentation conditions. The results from this analysis are shown here below in Figure 6. There is no simple (linear) function relating the response magnitudes to the physical contrast of the local color-surround configurations, as was found in some of our previous work (Dresp-Langley and Reeves, 2014a, b). However, the center-surround configurations with the weakest Weber contrasts ($<10$), produced the smallest magnitudes for “nearer” and “bigger” consistent with the pure contrast effects found previously with achromatic (no color) displays (Guibal and Dresp, 2004; Dresp-Langley and Reeves, 2012).

In the next analysis, the cumulated response magnitudes produced by the local color-surround configurations (A-L) were transformed into probabilities by dividing the cumulated response magnitude by the total number of independent observations ($N = 80$) for each local color-surround configuration. It was found that the higher cumulated response magnitudes, or probabilities, for “bigger” and “nearer” were systematically produced by a center color or tone (here red, blue and grey, as shown in Figure 4) on the darker of two surrounds in any of the six given pairs I-J to D-A (Figure 4). The corresponding probabilities of “nearer” and “bigger” were plotted as a function of the presentation condition (“black” wall and “white” wall), and are shown here below in Figure 7. It is found that, by comparison with the grey tone, the higher/highest probabilities for “nearer” and “bigger” are produced by the color red, the lower/lowest by the color blue.

The local color-surround configuration with the highest luminance contrast in the displays is blue-on-dark-blue (D), with a Weber contrast (64.38, Table 2). The local color-surround configuration with red-on-dark green (I) has a Weber contrast (16.9, Table 2) that is considerably, i.e. by more than a magnitude of three, weaker. Yet, it is found here that the probability of red-on-dark green to be seen as “nearer” or “bigger” compared with red-on-light green is significantly higher than the probability of blue-on-dark-blue compared with blue-on-light blue. This is shown by running Student’s $t$ test on the independent, cumulated response magnitude distributions produced by these two color-surround configurations in ten independent observers across independent display conditions in two independent presentation conditions (“black wall” and “white wall”).

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| Hue Combination                  | Weber Contrast |
|---------------------------------|----------------|
| Blue on Dark Blue “D”           | 64.38          |
| Grey on Dark Grey “L”           | 28.30          |
| Blue on Dark Grey “F”           | 25.15          |
| Blue on Dark Green “E”          | 25.15          |
| Red on Dark Grey “K”            | 16.90          |
| Red on Dark Green “I”           | 16.90          |
| Blue on Light Blue “A”          | 9.46           |
| Blue on Light Green “B”         | -0.33          |
| Grey on Light Grey “J”          | -0.38          |
| Blue on Light Grey “C”          | -0.45          |
| Red on Light Green “H”          | -0.54          |
| Red on Light Grey “G”           | -0.62          |

Table 2. Center-surround hue combinations and their luminance contrast (Weber) for the twelve paired local configurations in order of decreasing contrast magnitude.
respectively). The results of this analysis are shown here below in Figure 8.

In the final descriptive analysis, the probabilities of a given color/tone in a given surround configuration to be seen as “nearest” and/or as “biggest” of all in a given image display were sorted in the order of probability magnitudes, and plotted as a function of the color-surround configuration the color/tone was embedded in, and as a function of the presentation condition (“black wall” or “white wall”). The results from this analysis are shown here below in Figure 9. It is shown that the color red on the darker surround of two in a pair, and as a function of the presentation condition (“black wall” and “white wall”). The highest probabilities are produced by the color red (K and I), the lowest by the color blue (D, F and E). This probability distribution shows a clearer trend in the “black wall” condition (left) compared with the “white wall” condition (right). Response probabilities for the same color or tone on the lighter surround in a given pair are obtained by subtracting each of the probabilities plotted here from 1.

3. Discussion

The effect of the luminosity of the general background on local percepts of “nearer” and “bigger” found here is consistent with other findings on display complexity, sometimes also called articulation. Articulation refers to the proximity of a perceptual target, or reference surface, with higher/lower coplanar luminance, and/or to the spatial distribution of fields of illumination in complex displays. Studies testing predictions of coplanar spatial organization have shown, for example, that articulation can substantially increase local depth effects (Radonjić and Gilchrist, 2013), as is found here. Others have shown that the variability of color judgments decreases when 3D target cubes are embedded in a constant illumination background (Allred and Olkkonen, 2013). This suggests that in the real-world, or in photorealistic 3D scenes, adding uniform backgrounds strategically can improve the stability of color and related percepts.

The finding that red surfaces yield significantly higher probabilities for “nearer” and “bigger” compared with the blue surfaces here is consistent with previous findings by the authors in configurations with several surface patches of the same color against uniform gray backgrounds (e.g. Dresp-Langley and Reeves, 2015). The previous study had shown that this functional advantage of the color red disappears when played were fully saturated, and difference in luminance contrast does not account for the color effect here either (see the parameters in Table S3 in the supplementary materials). The most likely explanation of the statistically higher probabilities for “nearer” and “bigger” produced by the red surfaces here is one in terms of color temperature. An early study from the 1950ies had shown that cold color temperatures in
the range between 5400 and 6300 K require different physical adjust-
ments to yield subjective equality compared with warmer colors in the
range below 5000 K (Harrington, 1954). This suggests that cold and
warm colors are perceived as qualitatively distinct, with quantifiable
psychophysical correlates. It was also found that the difference in
perceptual effects elicited by warm and cold colors decreases with the
age of the observers. Such effects of ageing on artists’ use of color is
often reflected by a tendency, as they grow older, to make more
extensive use of vibrant warm colors, as brought forward by Werner
(1998) on the example of Monet. The effect of color temperature on our
perception may be ecologically driven and affect, directly or indirectly,
the subjective quality of a color. Ecologically relevance, or color quality
(‘attractive’, ‘repelling’ etc.) could determine a color’s probability to be
seen as “nearer” in a context where decision for action in response to
what is seen is mandatory. Magnitudes of foreground effects for red and
blue on a dark gray from this study in comparison with results from a
previous one (Dresp-Langley and Reeves, 2015) with the same colors,
but different displays and task constraints, are shown in Table 1 below.
In the previous study, we tested for effects of true colors on gray to
validate implicit assumptions relative Chevreul’s (1839) laws of color
and contrast. Observers had to compare complex multiple surface pat-
tterns of the same color displayed across light and dark gray back-
grounds presented sequentially in grouped and ungrouped pairs.
Average probabilities for a foreground effect (“nearer”) associated with
the colors blue and red on dark gray backgrounds are given as a function
of Kelvin. Selected reds and blues on dark gray had similar saturation
levels and Weber contrasts. The difference in Kelvin between the red
and blue is represented by values in the extreme lower and upper re-
gions of the Kelvin scale (°C), where higher values (°C) stand for colder
colors, and lower values (°C) for warmer colors.

Vasarely himself exploited such effects of color temperature, placing
warm against cold strategically in the plane to generate local variations
in relative depth where the warmer colors appear nearer to the observer
than colder tones. Photographers also exploit color temperature in this
way to produce similarly stunning perceptual effects, as shown here in
Figure 10.

As pointed out by Grossberg and Zajac (2017), the human brain
starts by responding to all image properties imperfectly first, and then

Figure 8. Cumulated response magnitudes for “bigger” (top) and “nearer”
(bottom) sorted in the order of response magnitudes for red-on-dark-green (I, as
in Figure 4) and blue-on-dark-blue (D, as in Figure 4). Despite the fact that D
has a local Weber contrast (Table 1) more than three times higher than I, the latter
produces significantly higher probabilities for “bigger” and “nearer”.

Figure 9. Response probabilities for a local color in a given surround to be seen as “biggest” (left) and/or “nearest” (right), plotted as a function of the presentation in
the “black wall” (top) and “white wall” (bottom) conditions. The color red on the darker surrounds clearly stands out as the “winner”, yielding the highest probabilities
for relative subjective depth (“nearer”) and relative subjective size (“bigger”).
uses hierarchical resolution of uncertainty whenever the sensitivity of
local detectors is insufficient to make sense of intrinsically ambivalent
physical image data. Specific multi-level interactions between de-
tectors accomplish such hierarchical resolution of uncertainty in
response to physical input, thereby generating the visual percepts that
we consciously see. The general conclusion here is that the brain does
not eliminate uncertainty too soon, but takes advantage of uncertainty
until processing stages are reached at which uncertainty can profitably
and drastically be reduced or eliminated (Erlikhman and Kellman,
2016; Silvestri et al., 2010). In the case of figure-ground perception,
when all other cues to visual depth in two planar configurations are
equal, the difference in temperature of a local color may become a
strategic cue to pictorial depth, as successfully captured and quantified
in this work here.

4. Conclusions

Vasarely’s oeuvre (1906–1997) set the standard for contemporary Op
Art and graphical design, and is a source of inspiration for current virtual
reality applications aimed at conveying realistic three-dimensional
qualities through non-dimensional representation projection of colour
and form in affine space. The configurations from this study, embedded
in larger, structurally ambivalent pictorial contexts, were inspired by
some of Vasarely’s creations (Figure 11), which are choice examples of
powerful effects of subjective variation in relative size and depth, gov-
erning the perceptual emergence of Gestalten by visual organization of
ambivalent image material into coherent representations of figure
and ground. The statistically significant correlation between perceptual so-
lutions for “nearer” and “bigger” found here in this study when no other
monocular depth cues are given in the planar image context is the
quantitative correlate of such visual organization. A warm red at the
center of configurations yields statistically higher probabilities for
“nearer” and “bigger” in comparison with a cold blue, suggesting that
colour temperature has an important functional role at a critical point in
the hierarchical perceptual resolution of figure-ground uncertainty in
complex 2D patterns. Color perception is a result of evolution (Yokoyama
et al., 2014), not exclusive to humans, and subject to differences across
cultures (Persaud et al., 2017). Also, species other than the human exploit
color information to survival specific purposes (Dresp and Langley,
2006). In man, as the ultimate expression of this evolution, color
perception is also linked to preferences, moods and emotions (Valdez and
Mehrabian, 1994). In context dependent shape perception, color may
compete with luminance contrast in resolving the planar ambiguity of a
complex image context. As suggested previously, there is no clear func-
tion relating subjective response magnitudes for relative depth, or size, to
the physical contrast of local color-surround configurations in complex
displays. Yet, configurations with the weakest luminance contrasts are
consistently the most likely to produce weaker depth effects. Pure
contrast effects were found previously mostly with achromatic (no color)
displays. The local color-surround configuration with the highest lumi-
nance contrast in the displays here, the cold blue-on-dark-blue, loses out
against the warmer red-on-dark green, although the latter has a three
times lesser Weber contrast.

Finally, any local effect of relative depth and/or size in a complex
pictorial context depends on the luminosity and complexity of the display
backgrounds it is presented on. This is quantified here in terms of the
significant difference between the “black wall” and the “white wall”
presentation conditions. Vasarely intuitively understood, and success-
fully exploited, all of the perceptual context effects described here.

5. Materials and methods

General aspects of the measurement approach and underlying
rationale are well documented in previously published work (Guibal
and Dresp, 2004; Dresp-Langley and Reeves, 2012, 2014a, b). Here, we
specify the materials and methods from which new analyses shown and discussed in the sections here above were drawn. The images (Figure 4) were computer generated and displayed on a high resolution color monitor (EIZO COLOR EDGE CG 275W, 2560 × 1440 pixel resolution) connected to a DELL computer equipped with a high performance graphics card (NVIDIA). Color and luminance calibration of the RGB channels of the monitor was performed using the appropriate Color Navigator self-calibration software, which was delivered with the screen and runs under Windows 7. RGB increments were controlled using ADOBE RGB in Photoshop 7. All luminance levels were cross-checked with an external photometer (OPTICAL, Cambridge Research Systems). The physical parameters (RGB, Hue °, Luminance (cd/m²), Saturation%, and X, Y, Z color coordinates) of the colors displayed here are provided in the supplementary Table S3. The size of each of the square surfaces in the center of each of the twelve local configurations in the image panels was 160 × 160 pixels and the size of each of the square surrounds was 400 × 400 pixels. The twelve local configurations were equally spaced, with 50 pixels between their surrounds, along the horizontal and vertical dimensions. The paired configurations in context are shown here above in Figure 4, displayed on black (“black wall” condition) and white (“white wall” condition) general backgrounds. The images were displayed centrally on a black or white general background of the 2560 × 1440 pixel screen. The size of a single pixel on the screen is 0.023 cm. Grey, red, and blue-green center squares on lighter and darker immediate surrounds were presented in pairs. Their position (left, right) in a pair as well as the position of each given pair in the global context was varied between presentations, sessions, and observers. Perceptually relevant Weber contrasts for each hue combination in the twelve paired configurations are given here below in Table 2.

Presentation on white (“white wall” condition) and black (“black wall” condition) general backgrounds was also counterbalanced between sessions and observers. The results shown here above originate from perceptual judgments of ten independent human adult volunteer observers with normal or corrected-to-normal vision from a culturally homogenous study population of young Europeans. A sample of ten is usually sufficient to yield statistically significant effects in strong perceptual phenomena, as found in all our previous studies on this topic. In such a case, it is neither necessary nor useful to include more subjects. To do so would be mandatory when looking for cultural differences in perception, which were not investigated here. The image variations were presented to observers individually and in separated sessions, with breaks between sessions. Each individual observer was tested for normal color vision using the printed version of the Ishihara Plates (Ishihara, 1917). After adaptation to the semi-dark room for ten minutes, the observer was comfortably seated in a semi-dark room in front of the EIZO monitor at a viewing distance of about one meter. Each individual observer received standard instructions for each perceptual judgment relative to “nearer” or “nearest” and “bigger” or “biggest”. Image presentation time was not limited. After a perceptual decision was made by typing the letter of the configuration chosen on the keyboard, the next image from a sequence appears on the screen one second later. The order of variable image contexts within and between sessions was varied in such a way that no single observer saw exactly the same context more than once in a session.

Declarations

Author contribution statement

B. Dresp-Langley: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

A. Reeves: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Competing interest statement

The authors declare no conflict of interest.

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