Pictorial balance is a bottom-up aesthetic property mediated by eye movements

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Abstract

Pictures evoke both a top down and a bottom-up visual percept of balance. Through its effect on eye movements, balance is a bottom-up conveyor of aesthetic feeling. Eye movements are predominantly influenced by the large effects of saliency and top-down priorities; it is difficult to separate out the much smaller effect of balance. Given that balance is associated with a unified and harmonious picture and that there is a pictorial effect known to painters and historically documented that does just that, it was thought that such pictures are perfectly balanced. Computer models of these pictures were created by the author and were found to have bilateral quadrant luminance symmetry with a lower half lighter by a factor of ~1.07 +/- ~0.03. A top weighted center of quadrant luminance calculation is proposed to measure balance.

To show that this effect exists, two studies were done that compared identical pictures in two different frames with respect to whether they appeared different given that the sole difference is balance. Results show that with observers, mostly painters, there was a significant correlation between average pair imbalance and observations that two identical pictures appeared different indicating at a minimum that the equation for calculating balance was correct. A conventional study of preference could not be done because of the necessity of using LED pictures that increase overall salience, and so decrease the aesthetic effect while retaining the effects on eye movements.

The effect is the result of the absence of balancing forces on eye movements. With painters who can disregard salience, the effect results from the absence of forces drawing attention to any part of the image. All parts of the picture including that in peripheral vision receive attention, and the eye seems to slide through rather than to jump from objet to object. The effect is being called pictorial coherency. Large tonally contrasting forms, geometric forms or many different forms that cannot be visually combined prevent the effect from being seen. Pictorial balance explains why viewing pictures cause fatigue. That pictures can evoke such a low level percept based on luminance would indicate that it belongs to a much earlier evolutionary development of the visual stream where an object is defined as a vector to detect movement.

Introduction

A picture, a bounded flat image, corresponds to nothing found in nature or mental imagery. This includes the borderless images in prehistoric caves (1). It differs from an image without borders in that it evokes the percept of balance: the parts relate to both the center and the borders (2). Balance is both a bottom-up percept and a top-down aesthetic concept taught in schools. But balance of what and how? Color, form or tonal areas have been proposed. These somewhat immeasurable qualities are said to be balanced around a geometric center or the principal pictorial axes and defined by a center-of-gravity type of equation. This is said to explain both the perception of balance and the aesthetic qualities of pictures (2,3,4). Any attempt to show that low level balance is determined by some sort of equation might be associated with this erroneous concept. It is either impossible or would require too much calculation for the visual system to do this. However, in the same way that elements of salience such as color, contrast, and orientation are used to calculate eye movements within a picture, one might be able to calculate balance as a function of pictorial properties (5).

Eye movements are predominantly influenced by saliency and top-down priorities (5,6,7). These determinants of eye movements are large so that it is difficult to distinguish the much smaller effect of balance. Locher and Nodine tried to do this by comparing eye movements in pictures that were thought to be balanced with variations of these pictures. Using trained and untrained observers, they found that trained observers had more diverse and fewer specific exploratory movements in the more balanced compositions (8,9,10). These effects are characteristic of better balance in that they indicate that the eye is less constrained to specific salient areas but do not quantify the effect of imbalance.

How the visual system determines pictorial balance can only be discovered empirically. I thought that this might be achieved by creating a perfectly balanced picture. Such a picture where balance has no effect on eye movements could be used as a base from which other measurements might be made. Perfect balance has also been used to explain the feelings of unity and harmony evoked by some pictures, and this corresponds to a very obscure effect observed by painters that does just that. There is no name or metaphorical description for the percept evoked by these pictures other than to say that they exhibit the aforementioned effect. It is to my knowledge only discussed when before such a picture in art schools. The unexpected change in a painting from being remarkably unified and harmonious to something less so or the reverse is quite striking. Peripheral vision seems to become more salient, creating the feeling that the whole picture can be seen at one time without any need to focus on any pictorial element. I call this percept pictorial coherence.

This was first noted by Roger de Piles, a French critic and painter around 1700 who described an arrangement of "lights and darks" in paintings creating an effect that is spontaneous and intense giving the impression that the viewer could gaze at the entire painting without focusing on any particular form (11). Cézanne apparently noted this. Indeed, his inability to describe this unnamed effect gives his conversations a cryptic quality (12, p.88-89, 110-111). Both Delacroix and Kandinsky give vivid descriptions of seeing such an effect in paintings (13,14, 15). (addendum A)

To study this effect I created computer models of images that evoke it through experience acquired from many years of painting. Image analysis indicated that the percept was obtained when an LED picture, centered at eye level and parallel to the plane of vision, has bilateral quadrant luminance symmetry with the lower half being slightly less luminant than the upper half by a factor of ~1.07 ± ~0.03 (where luminance is measured from 1 to 255 with black equal to 1 as measured by Photoshop CR2©).

A formula for balance can be derived from this: if a picture with bilateral quadrant luminance symmetry and a darker upper half can be said to be perfectly balanced i.e. its center of luminance is located at the geometric center of the picture, then the standard formula for the center of mass of four connected objects can be used. In this formula quadrant luminance L replaces the mass of each object with the picture centered at (0,0), L_{TOTAL} is taken as the average total luminance.

$$X = (X_{ULQ}L_{ULQ} + X_{URQ}L_{URQ} + X_{LLQ}L_{LLQ} + X_{LRQ}L_{LRQ})/L_{TOTAL}$$
$$Y = (1.07)Y_{ULQ}L_{ULQ} + (1.07)Y_{URQ}L_{URQ} + Y_{LLQ}L_{LLQ} + Y_{LRQ}L_{LRQ})/L_{TOTAL}$$
$$L_{TOTAL} = (L_{ULQ} + L_{URQ} + L_{LLQ} + L_{LRQ})/4,$$
$$\text{Balance} = \sqrt{X^2 + Y^2} \text{ or a vector } \vec{L} = (X, Y)$$

Luminance L is measured on a scale from 1 to 255 with 1 being black. The y values of the upper quadrants are modified by 1.07 to account for the increased visual weight of the upper half. X_{ABQ} and Y_{ABQ} are the coordinates of the center of their respective quadrants, and L_{ABQ} is a quadrant's average luminance.

While the aesthetic effect can be intense with a picture seen by reflected light, the percept is much less so in LED pictures. There is a diminished feeling of unity while the effect on eye movements is maintained. Because this is more subtle, a study of subject preference could not be done. This corresponds to the observations of Bertamini et al. who noted that observers preferred a print reproduction to seeing the same picture in a mirror or on a monitor, and they preferred the mirror view of the actual image to the image on an LED

screen (16). Locher et al made similar observations (17). LED images had to be used to permit precise luminance determination and reproducibility.

With respect to the effect an image framed with a white border against a black ground is seen as one visual object – the image and the frame. This is not true for a picture framed in black against a white ground. The former permits the comparison of a balanced framed picture with the identical picture in a slightly different frame that renders the combination unbalanced. This avoids the confounding variable of salience that occurs when an image is compared with even a small variant. Unfortunately, the white border also increases the saliency of the picture. If an observer is told to compare the two images and to disregard the frame, any perceived difference would be ascribed to the effect. Most people, who observed the two identical pictures in succession, saw no difference. Only a group of painters and a few people very interested in looking at pictures were found likely to see it. Two studies was done to show that those likely to see the effect in paintings could notice a difference within "identical pairs." A painting exhibiting coherence is said to be perfectly balanced; all others will be called unbalanced.

Materials and Methods

Each study consisted of ten pairs of images: Five in which one of the images was coherent and the other unbalanced (balanced or coherent pairs) and five in which both were unbalanced (unbalanced pairs). Images were prepared using Photoshop©. Quadrant image luminance characteristics can be changed in an unobtrusive and precise manner in Photoshop through the use of the level command on a small irregular form in which the luminance is usually changed by no more than ±5 percent. The form is then moved around until the desired quadrant value is reached. The two studies differed only in using different sets of white borders. The three possible image and border combinations are in Fig. 1. Study I compared figure 1a with either 1b or 1c. Study 2 compared figure 1b with 1c. Only the white borders are seen when a picture is seen against a black ground, and in the study the viewer sees only variations in the borders. Observers see sequentially a picture with one frame followed by the other on a calibrated iPad using the ColorTrue™ app and a Colorite™ device. The iPad image was also verified to have the stated luminance balance through measurement of screen shots. The observers viewed the iPad centered and parallel to the plane of vision at arm's length. The images on the iPad were approximately 5x6.75 inches and subtended visual angles of roughly 19º and 23º respectively under the conditions of the study. The pictures used for the studies are in Fig. 2. Images 1,3,5,7, 8 were the balanced pairs (all images are in the supplemental files).

Fig. 1 The three possible image and border combinations

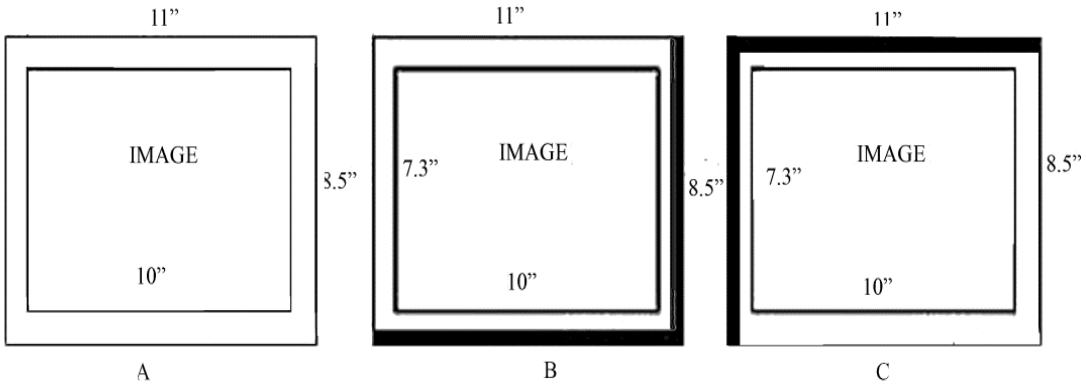

Fig. 2 Pictures used in the study pairs

The observers were predominantly artists of any age who gave their consent orally to participate in an anonymous study about how people look at pictures. They were told that it consisted of looking carefully at ten pairs of pictures and being asked whether the two central images appeared to be the same or different. They were also told that it was thought that some pairs might be seen as the same and others as different. No identifying information or medical history was obtained; there was no attempt to eliminate observers who were color deficient, had cataracts or had impaired binocular vision. The research study was done in accordance with the Helsinki Declaration (WHO). 45 observers were included in the first study and 39 observers in the second study. Other observers were excluded if they could not follow the directions and either rapidly said without careful examination that they could see no difference or if they insisted that the frame change was the only difference. There were only four of the latter. For pairs in which both pictures are unbalanced, it was presumed that observers would find the pictures to be identical so that the response of "same" was considered correct. With the balanced pairs a response of "different" would be labeled correct.

Observers viewed the pictures sequentially on an iPad at arm's length with the examiner seated slightly behind them. They were permitted, indeed encouraged, to hold the iPad themselves as long as it was maintained correctly centered and parallel to the plane of vision. There were no restrictions on the length of observation, and observers could return to a previous image as much as they wanted. However, subjects were told that the difference if any was more in the way of a feeling than a distinct difference and were discouraged from making point by point comparisons. The difference was described as analogous to that between monophonic and stereophonic music: same music but seems different.

Results and discussion

Four observers could identify all the balanced pairs correctly, and 5 observers made one error. (Table 1) Although it cannot be statistically proven, it is very suggestive that the effect is being seen. Some subjects thought they saw differences in color, one thought the depth of field was greater, and many saw differences but could not describe them.

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Table 1 the number of observers for each number of correct responses

1st study		2nd study	
Correct Responses	Observers	Correct Responses	Observers
10	3	10	1
9	2	9	3
8	2	8	1
7	4	7	6
6	13	6	9
5	12	5	11
4	7	4	5
3	1	3	1
2	1	2	2
Total	45		39

Among observers who perceived differences in any pair, many saw differences in both balanced and unbalanced picture pairs. Initially this was thought to be due to guessing. However, there is a correlation between the percent of pairs observed to be seen as different and the pair average distance (average imbalance). Pairs could be divided into two groups: one in which the average state of imbalance within the pair was small (the balanced pairs), and the other where the average imbalance was large. The balanced pairs were identified correctly by 40% of observers, and the unbalanced pairs were identified correctly by 75% of the observers. The correlation between average pair distance and the percentage identified as different was: $r(18) = -0.723$, $p < 0.001$. (Table 2).

This might verify the hypothesis that observers see pairs as different within balanced pairs. However, it might just indicate that observers see pairs that have low average pair imbalance as different from those having high average pair imbalance. One could verify this by constructing unbalanced pairs with an average imbalance no different from that found in coherent pairs.

If one were to select unbalanced pairs that contain particular types of salient features, then the results would be similar to image pairs 2 and 10 which most subjects saw as the same. These pictures are not only unbalanced but contain images such as the woman in white that strongly draw one's attention. Other forms that strongly attract ones attention for their formal properties will be discussed below. Therefore although table 1 might appear to show a Gaussian distribution, the answers are not a simple question of chance.

It is like the aforementioned analogy with monophonic and stereo music; one can place two speakers so far apart that anyone can identify a stereo effect or move them so close that no one can. One can liken the image pairs to pairs of flags extending in the distance until they appear to everyone to be one flag. Using this analogy one could say that the study does not distinguish between the people who see two flags and the few who become fascinated by what is painted on some. The results indicate at a minimum that the visual system sees pictures in terms of the formula of quadrant luminance balance that corresponds to distance in the analogy.

Additional image pairs can be found in the supplemental files.

Table 2 Pair average distance and percent of observers that identified the pairs as different.

	BALANCED PAIRS			UNBALANCED PAIRS		
	image pair	average pair distance	% correct/different	image pair	average pair distance	% different
1st Study	1	0.462	0.489	2	0.723	0.356
	3	0.318	0.356	4	1.894	0.289
	5	0.427	0.444	6	1.679	0.333
	7	0.509	0.378	9	0.944	0.178
	8	0.522	0.444	10	2.197	0.111
2nd Study	1	0.608	0.410	2	0.942	0.282
	3	0.652	0.359	4	2.153	0.154
	5	0.473	0.436	6	1.934	0.385
	7	0.658	0.282	9	1.389	0.256
	8	1.026	0.436	10	2.455	0.128
Mean		0.565	0.403		1.631	0.247
StDev		0.193	0.060		0.602	0.098

The use of an iPad in different lighting environments was necessary to bring the study to the observers as no laboratory was available. Reflections from the iPad screen increased the number of false negatives, i.e. coherent pictures being seen as unbalanced. The possibility of examiner influence cannot be excluded although an attempt was made to diminish this by being seated behind the subjects. The results of the unbalanced pairs were contrary to the expectation that no one would see the unbalanced pairs as different as seen in table 2. After all they are identical pictures. A MacNemar test showed data validity $p < 001$.

Pictorial balance is extremely sensitive to small differences of quadrant luminance which explains its fugacity without precise viewing conditions (table 3). Changing temperature of the lighting or height at which the painting is hung with respect to the viewer destroys the effect. With pictures in a studio even the drying of paint in the following twelve hours creates a tonal change that is sufficiently to make a coherent state disappear. Given that not everyone can see the effect that it is normally arrived at through chance, is usually fleeting and has no name would explain why it is not discussed in the 20th century literature.

Table 3 shows the lateral balance and top/down ratios for the 2nd study. The unbalanced pairs are in bold red.

Pair	lateral balance	top/down	pair	lateral balance	top/down
1	1.05	0.97	**6**	**1.04**	**1.37**
	1	1.06		**0.97**	**1.23**
2	**1.03**	**0.95**	7	0.94	0.97
	0.99	**1.01**		1	1.07
3	1	1.06	8	1	1.08
	0.93	1.16		1.1	1.26
4	**0.98**	**0.9**	**9**	**1.05**	**0.87**
	1.06	**0.83**		**0.98**	**1.01**
5	0.95	1	**10**	**0.8**	**0.96**
	1	1.07		**0.86**	**1.06**

Conclusions

When an innately sensitive observer views a picture ignoring saliency, balance remains to direct the eye. With perfect pictorial balance there is no controlling effect on eye movements. One becomes attentive to the whole picture and is able to move smoothly through it instead of being attracted to one form after another. This is what Roger de Piles describes as seeing the whole picture at one time "le tout ensemble" (11). It was found empirically that artists particularly painters had to be used as observers. This corresponds to results showing that painters view pictures differently than untrained individuals (10,18,19,20 ,21). Antes et al (19) showed that fixation patterns distinguish painters from non-painters, and Koide et al (22) using a prediction model of a saliency map showed

that artists are less guided by local saliency than non-artists. Coherence facilitates this in an extraordinary way. With the absence of forces drawing attention to any part of the image, all parts including that in peripheral vision receive attention.

With respect to eye movements I find that it is possible for the eye to glide seemingly smoothly through a coherent painting instead of jumping from place to place. During the study an observer who was clearly familiar with the effect in his painting but who did not identify the balanced pairs particularly well was taught to slide his eyes around. He then identified every pair correctly. For me the saccades (not micro saccades) themselves seem to be easier than with an unbalanced version of the same picture. By this I mean the intangible effort it takes to lift and move one's eyes from one part to another. It is simply less tiring to look at a more balanced picture, or conversely it is much more tiring to look at a very unbalanced picture. This might be shown by a study of how long subjects gaze at paintings of similar subjects with similar qualities of salient forms but with differing degrees of imbalance. No one complains of visual fatigue when intently watching a moving image on an LED screen, but they do when looking even briefly at pictures. Balance is irrelevant in a moving image while we are unaccustomed to the pull of imbalance in a picture and so experience it as eye fatigue.

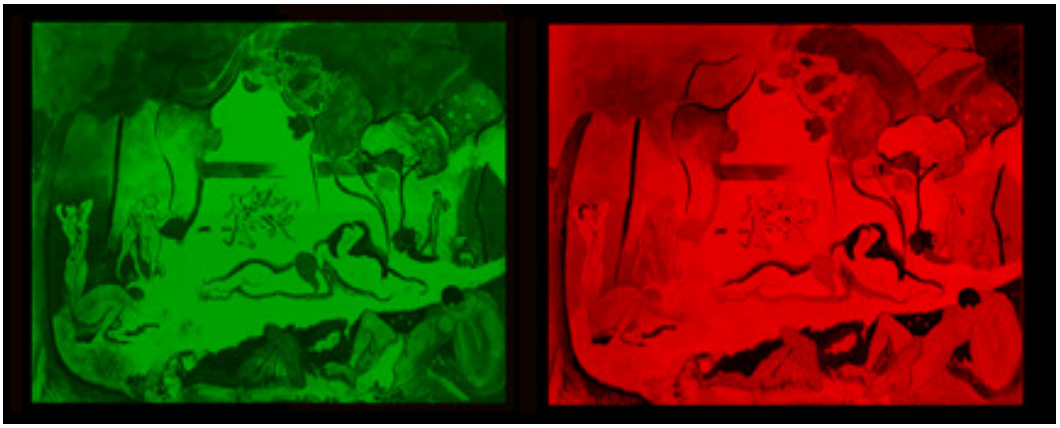
Geometric forms, strongly contrasting forms or many different prominent forms that cannot be combined conceptually into a few forms inhibit these eye movements. In the latter case the eye can learn to disregard a few major forms but cannot ignore many equally salient forms. While these pictures may meet the luminance balance criteria, they will probably not be seen or are much less likely to be seen as coherent. They prevent the viewer from disregarding salience. One could say that total pictorial imbalance is not simply a calculation of luminance balance but also a measure of the degree of low level or formal saliency.

A flat surface with no marks, i.e. one coated with a thick uniform layer of paint but modified so that the upper half is slightly darker, also cannot be seen or perhaps very weakly felt as coherent.. There has to be some surface quality for this part of the visual system to recognize an object. It has been shown that forms in nature have a fractal quality, that the visual system has evolved to respond to natural conditions, and that fractal images have an aesthetic quality (23,24,25). It can be inferred that the part of the visual system that calculates balance is also most sensitive to fractal forms.

An effect dependent on luminance would be expected to be mediated by the magnocellular visual stream which is highly sensitive to changes in luminance. This is substantiated by the percept disappearing in an environment of red light to which the magnocellular pathway is insensitive (26,27,28). The effect is not seen in a balanced

monochromatic red image where there are no blue or green pixels but is seen in a balanced monochromatic green image of the same picture (fig. 3). Binocular vision is necessary to view the percept. Images can be found in the supplemental files.

fig. 3 balanced monochromatic red and green pictures



Pictures are a very recent invention requiring technology to create flat surfaces (maybe 4th or 5th BC). They are not part of the evolutionary development of humans. Borders change an image into a picture, a visual object evoking the percept of balance. Since balance is a low level percept resulting from object luminance, it must have evolved for some other reason. It is proposed that an organism using the equation of balance could represent a complex object as a simple vector and follow it extremely rapidly. It would follow that the percept of balance is most likely the residual of a primitive visual system for evaluating object movement.

Addendum A

Eugene Delacroix:

"There is a kind of emotion which is entirely particular to painting: nothing [in a work of literature] gives an idea of it. There is an impression which results from the arrangement of colours, of lights, of shadows, etc. This is what one might call the music of the picture...you find yourself at too great a distance from it to know what it represents; and you are often caught by this magic accord. In this lies the true superiority of painting over the other arts [literature], for this emotion addresses itself to the innermost part of the soul…[and] like a powerful magician, takes you on its wings and carries you away." (13,14)

Wassily Kandinsky describes it, but without being aware of de Piles' observations which would have permitted him to understand his sensations, drew the conclusion that it resulted from the absence of recognizable objects:

"It was the hour of approaching dusk. I returned home … when suddenly I saw an indescribably beautiful picture, imbibed by an inner glow. First I hesitated, then I quickly approached this mysterious picture, on which I saw nothing but shapes and colors, and the contents of which I could not understand. I immediately found the key to the puzzle: it was a picture painted by me, leaning against the wall, standing on its side. The next day, when there was daylight, I tried to get yesterday's impression of the painting. However, I only succeeded half-ways: on its side too, I constantly recognized the objects and the fine finish of dusk was lacking. I now knew full well, that the object [objective form] harms my paintings." (15)

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