Pictorial balance is a bottom-up aesthetic property mediated by eye movements. A model of a primitive visual operating system explains visual balance and some aesthetics properties of pictures

David Corwin M.D.
dcorwinmd@gmail.com

Abstract

The concept of pictorial balance as a visual center-of-mass effect originated at the beginning of the 20th century to explain why some paintings evoke feelings of unity and harmony. It had never been mentioned in art commentary of the previous 500 years and is an unsubstantiated but widely assumed illusion. However, the visual basis for this illusion exists, and it is the object of this paper to explain what balance is and what it says about the visual system. A computer model was created of an unnamed pictorial effect known to painters when a picture feels unusually unified and harmonious. It was first described by a 17th century critic Roger de Piles, and there are descriptions of it by renowned artists. It was thought by the author that this effect was due to the painting being in a state of perfect balance. Computer modeling found that it had bilateral luminance symmetry with a lighter lower half by ~1.07 and that balance is based solely on luminosity. A study was done in which the identical picture in two different frames could seem different to subjects who viewed them in sequence; the sole difference being the total balance of the image. The study did not show that the subjects could see the effect but did show that the method of calculating balance using an algorithm was correct. It was found that low averaged balanced pairs could be distinguished from high averaged balanced pairs. This method views an organism as a collection of lights all moving together against a ground. This is divided by a vertical line into two equally luminous parts and further divided in half by a horizontal line. Four virtual lines are drawn parallel to the above two to create a picture. Light from each quadrant is spread to fill its respective quadrant, and the upper half is arbitrarily filtered to make it darker so that organisms illuminated from above would appear more balance. Balance is calculated by a center of quadrant luminance equation analogous to a center-of-mass calculation. It is suggested that object balance is a residual primitive visual processing system identifying organisms. An ecological explanation of the study is presented. Balance and the visual concepts involved can help painters create more visually attractive paintings if desired and for everyone to understand the neuro-aesthetic effects of paintings.

Introduction

Pictures are bounded flat images that correspond to nothing found in nature or mental imagery. This includes the borderless images in prehistoric caves[1]. They are a very recent invention requiring the technology to create flat surfaces (maybe the fourth millennium BC). They differ

from images without borders in that borders evoke 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. This paper is concerned with the bottom up perception of balance – the pre-emotional and pre-cognitive pathway from the retina to the primary visual cortex as Molnar postulated [3].

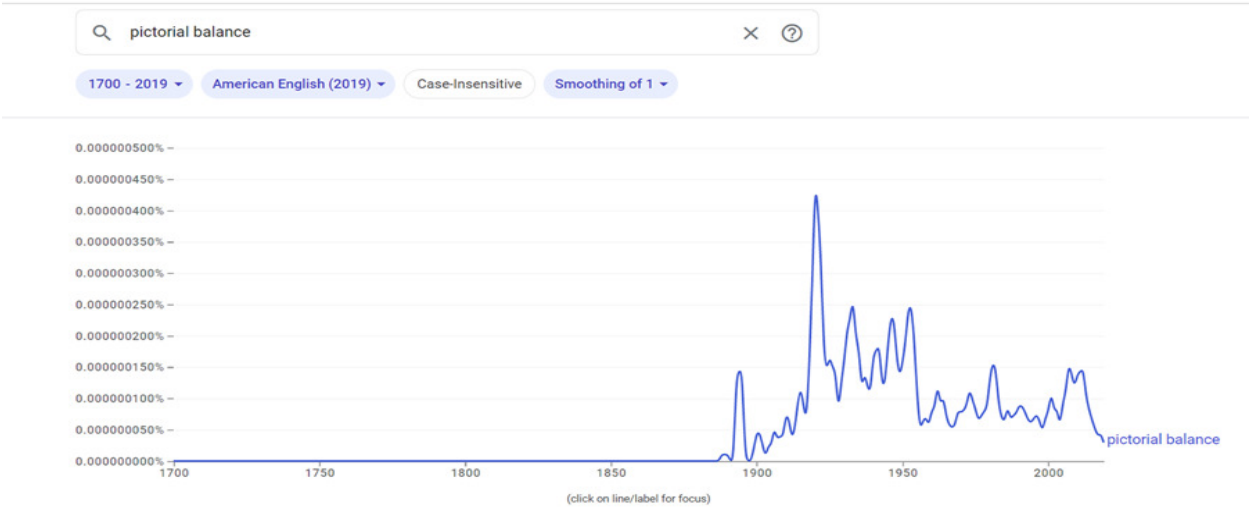
It has been stated that: "for centuries artists and writers on Western art have asserted that balance is the primary design principle for unifying structural elements of a composition into a cohesive narrative statement." A picture is considered balanced "if all its elements are arranged in such a way that their perceptual forces are in equilibrium about a fulcrum and if the fulcrum coincides with the center of the picture[4]." Objects, size, color, intrinsic interest, positions and apparent depth have been proposed as contributing to the aesthetic qualities of unity and harmony if they are balanced around the geometric center as calculated by a center of mass type of equation[2,4-6]. Rather than being a timeless observation, it is only an early 20th century concept related to artistic formal analysis that attempts to explain the effects of pictures without subject matter being involved.

Poore, a painter, was one of the earliest promoters of balance. However, he was most likely trying to explain the effect of bottom-up balance that I discuss in this paper in that he wrote:

> The whole of the pictorial interest may be on one side of a picture and the other side be practically useless as far as picturesqueness (sic) or story-telling opportunity is concerned, but which finds its reason for existing in the balance, and that alone.

Nothing in this "useless" side has the pictorial qualities described above, but for him they create in a particular picture a feeling that he calls balance[5]. There have been a number of recent studies that have tried to confirm this feeling of balance without success[7-9]. Both H. Locher and Puttfarken give comprehensive discussions of European theories of pictorial aesthetics between the 14th and the late 19th century in which balance is not mentioned[10,11]. This judgment of balance is inherently a modern top-down idea taught in schools. A Google ngram search for "pictorial balance" gives a good idea of this. While it only includes books scanned by Google, it exemplifies the above (see figure 1).

Figure 1. The frequency per year that "pictorial balance" was mentioned in books as scanned by Google by year



Balance has been thought to direct the eye, but the force that strongly influences eye movement is salience. A sequence of saccades can be predicted through calculations based on the most salient features of surrounding areas, and this has been correlated with eye tracking[12-14]. There have also been studies that tried to show the more subtle effect of balance. Locher and Nodine compared eye movements in pictures that were thought to be balanced with variations of these pictures. They found that trained observers had more diverse and fewer specific exploratory movements in the more balanced compositions than untrained observers. On the other hand, in his extensive study of tracking eye movements, Buswell could find no difference between the two groups. The duration of fixations and the length of saccades are usually discussed in top-down cognitive terms of subject comprehension or artistic judgment unrelated to balance[15-19]. Balance has a different sort of effect that is discussed below.

While this concept of balance is a simple intellectual exercise, a top-down effect, the feeling of balance could not exist without some basis in reality. In order to understand and measure low level balance one must start with a picture that exhibits the sensation of perfect balance. Balance has been used to explain the feelings of pictorial unity and harmony, and this corresponds to an 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 unnamed effect. It is usually only discussed in art schools when standing before such a picture and the feeling is created. The unexpected change in a painting from being remarkably unified and harmonious to something less so or the reverse is quite striking. It creates the feeling that the whole picture can be seen at one time; the gaze moves smoothly around without the need to concentrate on any pictorial element. There is a qualitative difference between a perfectly balanced and a somewhat unbalanced painting where the gaze is forced to go from one object to another. As the picture becomes progressively balanced the gaze moves easier. I will call this effect pictorial coherence.

Because it has had no name historical discussion of it has been limited. Roger de Piles, an 18th century French critic and painter described arrangements of "lights and darks" in paintings creating an effect that is spontaneous and intense, riveting the attention and giving the impression that the viewer could gaze at the entire painting without focusing on any particular form. He thought this was the primary aesthetic effect of a painting[11]. Both Delacroix and Kandinsky give vivid descriptions of seeing paintings that exhibit this[11,20,21] . Cézanne apparently noted it; his inability to describe it gives some of his conversations a cryptic quality[22]. (Addendum A).

To study this effect I created computer models that evoke it, through experience from many years of painting based on observations that it had to have bilateral luminance symmetry with a slightly darker upper half. Image analysis indicated that the percept was obtained when a picture, centered at eye level and parallel to the plane of vision, has this symmetry with the lower half being slightly more luminous by a factor of 1.07 ± ~0.03 (where luminance is measured from 1 to 255 with black being zero as measured by Photoshop© CR6). A perfectly balanced painting will be described as coherent; all others will be called unbalanced for the study's first objective.

With respect to balance it was discovered by accident that the visual system cannot distinguish a picture from its white frame. I had printed black and white pictures that appeared coherent whether framed or cut out. Due to an error of alignment the framed image appeared unbalanced while the cut out image remained balanced. It was derived from this that with respect to balance, pictures are defined only by luminosity and not lines. For example, this is not true for an LED picture framed in black on a white ground where black marks the end of the picture.

There is a theoretical formula for balance which explains observations of a center-of-mass like effect: if a rectangular picture with bilateral quadrant luminance symmetry and a darker upper half is said to be perfectly balanced around the geometric center, then the standard formula for the center of mass of four connected objects can be used. In this formula quadrant luminance L_{xxQ} replaces the mass of each object and is located at the geometric center (center-of-mass) of the respective quadrant. For simplicity, the picture's geometric center is located at (0,0). L_{TOTAL} is taken as the average total luminance.

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

Y values of the upper quadrants are modified by 1.07 to account for the increased visual weight of the upper half. X_{XXQ} and Y_{XXQ} are the coordinates of the center of their respective quadrants, and L_{xxQ} is a quadrant's luminance. The equation can be expressed as an addition of four vectors $\vec{L} = (X,Y)$. Although this equation is precise for defining perfect balance, it is not clear whether

it is true for states of imbalance. This will be called the geometric method of determining balance.

Another way of calculating balance is derived from the idea that it is based solely on luminance and would have evolved from a primitive method for identifying and following moving organisms i.e. fish. They are defined as collections of luminous points that move together with respect to a ground. If one were to divide this into two equally luminous parts by a virtual vertical line which is itself bisected horizontally by another virtual line, the object is divided into four parts.li Virtual lines parallel to the preceding ones are drawn enclosing the object to create a "picture." The luminance of the upper half would be arbitrarily decreased relative to the bottom half by a factor possibly to account for light coming from above so as to render the organism more balanced and the light energy or amount of light is averaged over its respective quadrant. This allows the formulation of vectors of luminance and the calculation of balance according to the geometric method. This second method is called the biological method of balance.

There are two effects conveyed by balance: the sometimes intangible effort for the eye to move across the picture and an attention riveting effect. Both contribute to a feeling of unity and harmony. With a picture seen by reflected light, the two seem inseparable. However an LED picture is a poor conveyer of the attention riveting effect while it maintains the effect on eye movements. This would explain the study of Bertamini et al. who noted that observers preferred a print reproduction to the same picture as seen in a mirror or on a monitor and that they preferred the mirror view of the actual image to the monitor image[23]. Locher et al. made similar observations[24]. The only difference between these three situations is that the light emitted from an LED screen is polarized. Misson and Anderson showed that polarized light alters luminance contrast perception[25]. This in some unknown manner interferes with the attention riveting aesthetic effect so that it cannot be measured using observer preference. However feelings evoked by the ease of movement are experienced allowing a performance based study to determine whether two identical pictures were the same or different with balance being the only difference. LED images had to be used to permit precise luminance determination and reproducibility under the conditions that were feasible. Printed pictures could not be shown to have the stated luminance properties under such conditions.

The first object of this study was to show that some people are able to see this state of perfect balance, pictorial coherence, by showing that they perceive a difference in two identical pictures differing only because one is perfectly balanced. The second later objective was to show that one or both calculations of pictorial balance are valid by showing that the study group is able to distinguish fine degrees of pictorial imbalance using these definitions

Materials and Methods

Since a white framed picture is seen by this low level visual system as one object while the top-down view sees it as a picture in an uninteresting frame, the comparison of a balanced picture with the identical but unbalanced picture can be done by a slight change of frame. If an observer compares carefully the two images and is able to disregard the frame, any perceived difference would be ascribed to the effect. It was presumed that the pairs of unbalanced pictures would be indistinguishable because initially I did not think that observers could see degrees of imbalance within the pairs. Many potential observers were eliminated because they did not pay full attention to the pairs. They would glance at the pictures rapidly deciding there was no difference. Observers were included in the analysis if they carefully inspected the pictures whether they saw any difference or not. It was noticed that painters and those interested in looking at pictures would observe the pictures carefully. Two studies were done using different frames.

Each study consisted of ten pairs of images: five, in which one of the images was perfectly balanced (balanced pairs), and five in which both were unbalanced (unbalanced pairs). Images were chosen because they seemed to have predominantly neutral content. They were prepared using Photoshop©. Quadrant image luminance can be changed in an unobtrusive and precise manner through the use of the level command on an 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 2a with either 2b or 2c. Study 2 compared figures 2b with 2c. The observer viewed sequentially a picture with different frames on a color-calibrated iPad3 using the ColorTrue™ app and a Colorite™ calibration device. The observer viewed the iPad centered and parallel to the plane of vision at arm's length. The images on the iPad were approximately 5 x 6.75 inches. The pictures used for the studies are shown Fig. 3, and this is the order in which they were seen. Images 1,3,5,7, 8 were the balanced pairs. (all images are in the supplemental files with accompanying quadrant luminance data)

Fig. 2 The three possible image and border combinations: the solid black lines would not be seen on a black ground.

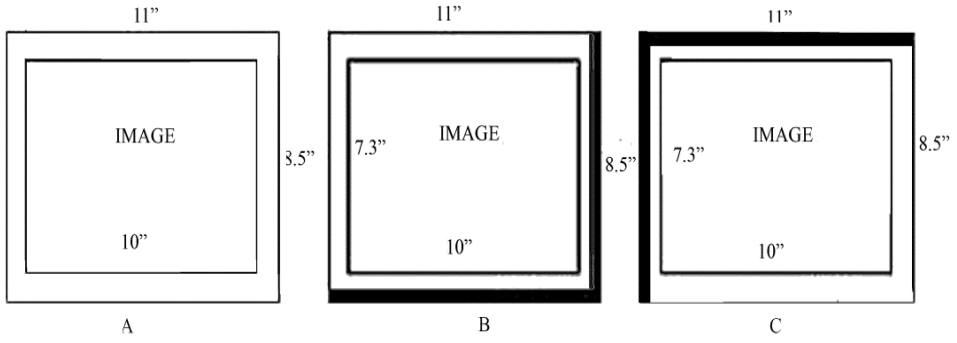


Figure 3 Pictures used in the study pairs

The observers gave their verbal consent to participate anonymously in a study about how people look at pictures. They were told that it would consist of looking carefully at ten pairs of pictures and being asked whether the central images appeared to be the same or different while disregarding the frames. They were told that it was intended for some pairs be seen as the same while others as different. No identifying information or medical history was obtained, and there was no attempt to eliminate observers who were color deficient, had cataracts or had impaired binocular vision. 45 observers were included in the first study and 39 observers in the second study. Observers were excluded if they did not follow the directions by either rapidly saying without careful examination that they could see no difference or by insisting that the frame change was the only difference. There were only four of the latter. For the unbalanced pairs it was presumed that because of slight differences of imbalance, 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 indicating they had seen the effect.

Observers viewed the pictures sequentially on an iPad at arm’s length while I sat 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 they 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 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). Some subjects thought they saw differences in color. One thought the depth of field was different, and many felt there were differences but could not describe them. These results do not indicate that observers perceived the percept of perfect balance because the study is not sufficiently statistically powerful. It would have required many more pairs and is as shown below strongly influenced by the degree of imbalance in the unbalanced pictures**.**

Table 1 the number of observers answering correctly the 10 pairs in the study

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

It was noticed to my surprise that subjects saw differences in the unbalanced pairs. At first I thought this was due to guessing, but a further analysis indicated that there is an inverse correlation between the percent of pairs observed as different and the pair average distance (average imbalance) as calculated with the two methods (see table 2). The pairs can be divided into two groups based on balance: one in which the average state of imbalance is small (the

balanced pairs), and the other where the average imbalance is large. The correlation for the geometric determination between average pair imbalance and the percentage identified as different is: $r(18) = -0.676$, $p = 0.001$. The same correlation for the biological determination is $r(18) = -0.757$, $p < 0.001$. The more balanced the picture pairs, the less likely they are to be seen as the same.

The correlation of the pair average balance with observations of same or difference is not obviously logical. One might think that they would be comparing one of the pair with the other so that the intra-pair difference would correlate with being seen as different. However, there is no correlation; the reason for this and the ecological meaning of the study will be discussed below.

Table 2 Pair average distance and percent of observers who identified the pairs as different using both the Geometric method and biological method of balance. The MATLAB™ code and corresponding pictures without black borders used to calculate the al balance is in the supplemental files.

		BALANCED PAIRS				UNBALANCED PAIRS		
		geometric distance average	visual average distance	% Seen as different		geometric average distance	visual average distance	% Seen as different
1st Study	1	8.81	8.66	0.49	2	11.39	15.72	0.36
	3	5.00	6.50	0.36	4	29.70	36.18	0.29
	5	6.97	11.06	0.44	6	26.36	30.90	0.33
	7	7.97	8.24	0.38	9	14.88	16.08	0.18
	8	8.08	8.05	0.44	10	25.98	39.02	0.11
2nd Study	1	2.92	11.15	0.41	2	14.67	19.60	0.28
	3	10.15	13.13	0.36	4	33.50	41.25	0.15
	5	7.35	9.92	0.44	6	30.09	29.15	0.38
	7	10.24	13.42	0.28	9	21.62	22.62	0.26
	8	15.96	15.76	0.44	10	38.19	42.68	0.13
average		8.34	10.59	0.40		24.64	29.32	0.25
StDev		3.48	2.88	0.06		8.83	10.35	0.10

The ability to see pairs as different as a function of their average imbalance is true for the observers selected for their ability to follow the rules and who were mostly painters. This

correlates with studies showing that painters view pictures differently than untrained individuals [26-32]. Antes showed that fixation patterns distinguish painters from non-painters, and Koide et al using a prediction model of a saliency map showed that artists are less guided by local saliency than non-artists so that the effects of balance would be more manifest[27,32]. From my experience, when shown pictures, painters become much more involved in the act of looking than non-painters.

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 as the reflections change quadrant luminance. It is highly unlikely that the reverse would be true. That observers saw unbalanced pairs as being different was contrary to expectations, and therefore could not have been influenced by the examiner. A MacNemar test shows data validity $p < 001$.

Observations

Many painters are either trained to or instinctually do follow their eye as it moves around a picture. It does require practice to look at pictures carefully; it is hard work. Balance exerts an unaccustomed force on the eye muscles. Subjects constantly complained of it such that a study involving more than 12 pairs at one time is difficult. As mentioned above it has been a standard concept that the effect of balance on eye movements might be objectified with eye tracking by viewing the identical picture with two or more different states of imbalance. The study indicated that this would not be expected to be true. There was no difference within the pairs although it might be true if one of the pictures is perfectly balanced.

Perfect pictorial balance, a coherent picture, is extremely sensitive to small differences of quadrant luminance. This explains its fugacity without precise viewing conditions (table 3). Changing the illuminating light spectrum or its height relative 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 cause the effect to disappear. Given that not everyone sees the effect which is normally created through chance and even then is fleeting, and that there is no name for it, one can understand why it is not discussed in the 20th century literature.

A flat surface with no marks, i.e. one coated with an opaque layer of paint gradually modified so that the upper half is slightly darker, cannot be seen as coherent. If one calculates backwards from the perceived balance i.e. the original viewed object unmodified by the visual system, it would present itself as a uniformly colored object. 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 fractal images have an aesthetic quality and that the visual system has evolved to respond to conditions of nature that are fractal[33- 35]. Therefore, it can be inferred that the part of the visual system that calculates balance is also most sensitive to fractal forms. The

visual system is designed to work best in this fractal environment and not the world of manmade objects that are linear and uniform, causing the eye to jump from one form to another. Pictures with uniformly colored geometric forms having no fractal qualities or those with many equally prominent forms detract from balance. Pair 2 is a good example of this. The eye is forced to go from form to form with perhaps slightly greater ease as balance improves. Geometric forms are usually solid unvarying colored forms that strongly attract the eye and do not exist in nature. It has been noted that binocular vision is necessary to view the percept.

As previously suggested, the algorithm used to calculate balance can be seen as an evolutionary method to identify and follow a moving object i.e. a fish. The object would be identified by its vector and its virtual rectangle. The ability of the visual system to create virtual lines has been documented in the Kanizsa illusion. This illusion has been shown to be seen by sharks, the oldest extant jawed vertebrates as well as insects and birds, so that the creation of virtual lines has been programmed into our visual system since the beginning[36]. Once these measurements are done the visual system has "lock on" to the organism and can follow its changes. A complex object of whatever size is reduced to an ever changing vector and rectangular halo. Even if it stops moving, the vector and rectangular halo would remain visible where it might otherwise blend in with the ground. Many different moving forms can be followed simultaneously with minimal computing power. This provides an ecological explanation of the study: the pictures are being seen and interpreted as moving organisms. A vertebrate, a bilaterally symmetric organism presenting with a low average balance would be seen as possibly an predator approaching. Particular attention would thus be directed at the two images so that they would be seen as different. However, a high averaged imbalanced image pair would be interpreted as an organism moving somewhat orthogonally with no threatening quality. The two images would be seen as inconsequential variations of the same organism and identified as being the same.

In LED pictures there is a decoupling of two low level aesthetic effects. One relates to the ease of making eye movements and is not inhibited by polarized light. The other rivets the attention in an involuntary way when perfectly balanced and in varying degrees as the picture becomes imbalanced. This latter effect is inhibited by polarized light. Humans can perceive balance, and their perception can be explained by a simple algorithm. In the phylogenic development of vision, this algorithm would be a simple way to organize the world of moving organisms. Primitive vertebrates perceive virtual lines that are related to the perception of balance. Therefore, there must be neurons that can perform these calculations. The anatomical location for both neurons that perceive balance and a pathway that rivets the attention might be discovered by using fMRI imaging with a subject viewing a projected balanced picture through both a polarizing filter and a neutral density filter. Based on work by Wu et al. and Duchemin et al, the calculation of balance and its effect on eye movements might be located in the pretectal area of the midbrain. This has been shown to be a major center of global motion processing[37,38].

The attention riveting effect is, as so eloquently described by Delacroix, an artistic peak effect different but similar to the peak effects in other art forms. These can be riveting in their own way and so may have a common pathway[39-41]. A "peak artistic experience" is characterized by the work commanding total involvement and concentration to the exclusion of everything else. It has aspects of a dissociative experience like that described by Brantley[39]. A neuropsychological definition of art is a collection of colored spots in a picture, sounds as in poetry and music, objects, dance, etc organized so as concentrate the attention to the extent that it becomes at its maximum intensity a dissociated experience.

There is, however, no such thing as Art. There are only the arts. The aesthetic response may have a common pathway, but no one is highly sensitive to every art form. Clive Bell in his book ***Art*** describes his marked emotional sensitivity to painting in comparison to his lack of sensitivity to music. He can enjoy and intellectually understand why a musical composition or a performance is excellent, but it is not the same as his response to painting. He can make this distinction only because he had this acute sensitivity to painting to which he could compare other responses. Without that he might have expected that any aesthetic response is an intellectual one[42]. This distinction between emotional and intellectual response is fundamental to the understanding of an art form and this paper, and it is a source of much confusion.

The author would like to thank the Matlab Mathworks Help community for writing the code for calculating the biological method of balance.

Supplemental Information is available for this paper with the pictures, calculations of balance, and statistical studies permitting complete reproducibility. There are additional pictures that can be used to test various hypotheses. More can be provided on request.

Correspondence should be addressed to David Corwin dcorwinmd@gmail.com

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 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[11,21]."

Wassily Kandinsky describes the effect, but being unaware 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. As I was returning 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…that the object [objective form] harms my paintings"[22].

Cézanne's comments about painting are most frequently recorded in conversations in which he repeatedly insisted that a painter must paint from nature[16]. However, his paintings are notable for their distortions especially the series of bathers in which both people and nature have been abstracted. Forms in nature as opposed to man-made forms have a fractal nature and do not have particularly salient properties[33]. I believe Cézanne was attempting to compose balanced pictures that enabled the gaze to move through them smoothly as it does when we look at natural scenes. It would seem that he had no vocabulary to express this other than to say one must paint from nature.

Addendum B

The biological method permits the determination of balance in non-rectangular pictures or those seen at an angle. The solution to the calculation of perfect balance in non-rectangular pictures is demonstrated with fig. 3. Previously I could only determine this empirically. The lower half is identical to the lower half of the balanced picture fig 4. Both have a luminance of 124.8 (the average pixel value). The upper half of fig 4 has a luminance of 115.5. Were this image to be balanced then the upper half of fig 3 would have to have a luminance of 115.5. However, if the light energy or luminance flux is spread out over the total area that includes the black rectangles then the luminance of the total upper half including the black areas will be less. This is calculated as follows: the luminance of 115.5 multiplied by the number of luminous pixels of just the upper half of the picture is equal to the luminance **L** of the upper half including the black rectangles multiplied by the pixel area of the upper half.

(189,360-54,000) x 115.5=189,360 x **L**, so that **L** = 82.6. (black areas of the upper half have a luminance of zero).

Changing the upper right and left quadrants of figure 3 so that their pixels have an average luminance of 82.6 (including the black rectangles) somewhat paradoxically creates a balanced picture.

Figure 3 the calculation of luminance in non-rectangular objects. The dimensions of the image is 526 x 720 pixels and each black rectangle is 150 x 180 pixels

Figure 4 – figure 3 without the obscuring black rectangles

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