Pictorial balance is a bottom-up aesthetic property mediated by eye movements. A theoretical model of a primitive visual operating system could explain balance.

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Abstract

This paper identifies a specific pattern of luminance in pictures that creates a low level neuro-aesthetic effect and provides a theoretical explanation for how it occurs. Given that pictorial balance is associated with a unified, 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 found to have bilateral quadrant luminance symmetry with a lower half lighter by a factor of ~1.07 +/- ~0.03. Two different methods are proposed to calculate balance. A study was done comparing the identical picture in two different frames with respect to whether they appeared different given that the sole difference is balance. Results show that with the observers, mostly painters, there was a significant correlation between average pair imbalance and the appearance of difference indicating at a minimum that these methods can be used for calculating pictorial balance. For those who can disregard saliency the effect is the result of the absence of forces on eye movements created by imbalance. The unaccustomed force invoked by imbalance causes fatigue when viewing pictures carefully. The second method enables calculations in non-rectangular pictures and could be a primitive visual operating system allowing complex vector and topological analysis of objects.

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]. They are a very recent invention requiring the technology to create flat surfaces (maybe 4^{th} or 5^{th} 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. But balance of what and how? Color, form or tonal areas have been proposed. These somewhat immeasurable qualities have been said to be balanced around a geometric center or the principal pictorial axes and defined by a center-of-gravity type of equation that explain both the perception of balance and the aesthetic qualities of pictorial unity and harmony [2, 3, 4]. This is neurologically impractical. Any attempt to show that low level balance is determined by some sort of equation might be associated with this erroneous concept. 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 so that it is difficult to distinguish the much smaller effect of balance [5, 6, 7]. Locher and Nodine tried to show 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 trained eye is less constrained to specific salient areas but do not quantify the effect of imbalance.

I thought that one approach to the problem was to create a perfectly balanced picture where balance has no effect on eye movements. As mentioned perfect 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 effect. It is only discussed in art schools when standing before such a picture. 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 eye moving smoothly around without the need to focus on any pictorial element. I call this percept pictorial coherence.

Roger de Piles, an 18th century French critic and painter first describe this effect as 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 effect gives some of his conversations a cryptic quality [12, p.88-89, 110-111]. Both Delacroix and Kandinsky give vivid descriptions of seeing paintings that exhibit it [13, 14, 15] (Addendum A). To study this effect I created through experience acquired from many years of painting computer models of pictures that evoke it. Image analysis indicated that the percept was obtained when a picture, centered at eye level and parallel to the plane of vision, has bilateral quadrant luminance symmetry with the lower half having slightly more luminance than the upper half 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).

It is the object of this study to prove this by showing that subjects can distinguish a perfectly balanced picture from the identical picture that is imbalanced. While the aesthetic effect can be intense with a balanced picture seen by reflected light, the visual difference in LED pictures between the two is not so great as to evoke an obvious difference in observer preference. However, the effect on eye movements of the balanced picture is maintained so that the two images should feel different. The problem with LED pictures is shown by the study 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 that they preferred the mirror view of the actual image to the image on an LED screen [16]. Locher P, Smith JK, et al. [17] made similar observations. This can be explained by the light emitted from an LED screen is polarized to which humans are sensitive. Misson and Anderson [18] showed that polarized light alters luminance contrast perception. This in some unknown manner interferes with the aesthetic effect. However, 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. If an observer compares the two images and is able 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 who were very interested in looking at pictures were found likely to see it. Two studies were done using different frames. A painting exhibiting coherence is said to be perfectly balanced; all others will be called unbalanced.

There is a theoretical formula for balance which is derived from the perceived state of perfect balance and explains observations implying a center-of-mass-like effect: if a rectangular 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_{xxQ} replaces the mass of each object or quadrant and is located at the geometric center of the respective quadrant. For simplicity, the picture's center is 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_{ABQ} and Y_{ABQ} are the coordinates of the center of their respective quadrants, and L_{ABQ} is a quadrant's luminance. The equation can be expressed as an addition of four vectors $\vec{L} = (X, Y)$ This will be called the geometric way of determining balance

Although this equation is precise for the state of perfect balance; it is not clear whether it could be applied accurately to pictorial states of imbalance. In addition, just as with the center-of-mass calculations I did not think that the visual system could do these calculations either. Another way of calculating balance is derived from the idea that balance is a low level percept of luminance. It could have been an early life method for following moving objects 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 vertical line which is itself bisected perpendicularly by another line, the object is divided into four parts. Lines parallel to the preceding ones are drawn enclosing the object to create a "picture." The luminance of the upper half would be arbitrarily diminished relative to the lower half by a factor (~1/1.07 in humans) so that a uniform light source would not be seen as balanced. The light energy from each quadrant is spread over its area creating vectors of luminance that permit the calculation of a vector of balance. The ability to draw imaginary lines has been demonstrated in vertebrates as primitive as the shark that can see the illusion of kanizsa figures [19, 20]. This second method is called the visual method of balance.

The visual system identifies the object by this vector and the virtual rectangle which represent all the points of light that make up the object. Although this is constantly changing, once done the visual system has "locked on" to it and can therefore distinguish it from all the other points of light. A complex object of whatever size is reduced to moving vectors and an illusory rectangle. Even if it stops moving, the vector and rectangular halo would remain visible where it might otherwise blend in with the ground. The rectangle guarantees that at any moment either the prey or predator is located within its boundaries. This model explains how balance has evolved to have an effect on eye movements. It also permits the determination of balance in non-rectangular pictures or those seen at an angle.

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 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. Observers view sequentially a picture with different frames whose widths are slight different on a color calibrated iPad using the ColorTrue™ app and a Colorite™ calibrating device. 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 19° and 23° 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

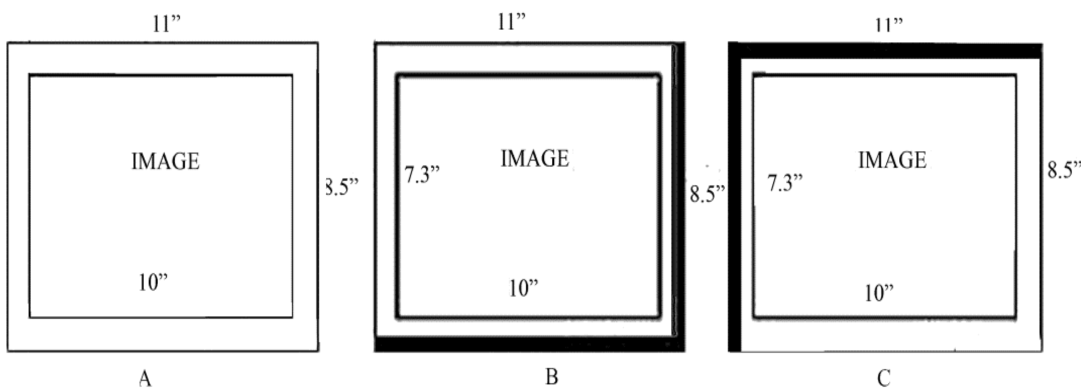

Figure 2 Pictures used in the study pairs

The observers were predominantly artists of any age who gave their consent to participate in an anonymous study about how people look at pictures. It was done in accord with the provisions of the Declaration of Helsinki. They were told that the study was about how people look at pictures and 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. They were 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. 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 by either rapidly saying without careful examination that they could see no difference or if by insisting 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 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 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 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 different, and many saw differences but could not describe them.

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 can be divided into two groups: one in which the average state of imbalance within the pair is small (the balanced pairs), and the other where the average imbalance is large. The balanced pairs were identified correctly by 40% of observers (observers who saw a difference), and the unbalanced pairs were identified correctly by 75% of the observers. The correlation for the geometric determination between average pair distance and the percentage identified as different is: $r\ (18) = -.722$, $p < 0.001$. The same correlation for the visual determination is $r(18) = -0.657$, $p = 0.0016$ (see supplementary files for the MATLAB™ code used to calculate the visual balance)

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 4 and 10 which most subjects saw as the same. These pictures by Matisse and Gauguin are not only unbalanced but contain salient contrasting images such as the woman in white (image 10) that draw one's attention. However, I am sure the paintings would not normally be thought of as being unbalanced. Other salient types of forms or groups of forms will be discussed below.

While table 1 might appear to show a Gaussian distribution, the answers are not simply due to 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 also 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 this particular study does not distinguish between the people who see two flags and the few who become fascinated by what is painted on them. The results indicate at a minimum that the visual system sees pictures in terms of one of the two formulas of luminance balance or a variation of them that corresponds to distance in the analogy. Additional image pairs with lower/upper ratios closer to 1.03 or 1.10 can be found in the supplemental files.

Table 2 Pair average distance and percent of observers that identified the pairs as different using the geometric method. The visual method values can be found in the supplementary files.

Table 2 the pair distance and the percent found different for balanced pairs and unbalanced pairs

		BALANCED PAIRS				UNBALANCED PAIRS		
		geo-metric distance average	visual average distance	% different		geo-metric average distance	visual average distance	% different
1st Study	1	3.58	11.79	0.49	2	5.69	15.19	0.36
	3	2.50	14.92	0.36	4	14.85	29.30	0.29
	5	3.48	11.06	0.44	6	13.18	28.11	0.33
	7	3.98	13.29	0.38	9	7.44	12.44	0.18
	8	4.04	16.42	0.44	10	17.24	27.20	0.11
2nd Study	1	4.73	15.01	0.41	2	4.73	19.09	0.28
	3	5.07	22.53	0.36	4	5.07	38.59	0.15
	5	3.68	12.39	0.44	6	3.68	26.48	0.38
	7	5.12	13.38	0.28	9	5.12	20.46	0.26
	8	7.98	9.19	0.44	10	7.98	34.37	0.13

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 they increase the luminance. The possibility of examiner influence cannot be excluded although an attempt was made to diminish this by being seated behind the subjects. That observers saw unbalanced pairs as being different was contrary to expectations (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 unvarying viewing conditions (table 3). Changing the spectrum of the illumination or the height of the painting 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 sufficient to make a coherent state disappear. On the other hand, the effect can appear at times in a picture when viewed at some particular angle or under a particular illumination. These pictures will not appear balanced when viewed in any other way. Given that not everyone can see the effect, that it is normally arrived at through chance, that it is usually fleeting and that it has no name would explain why it is not discussed in the 20^{th} century literature.

Table 3 shows the lateral balance and top/down ratios for the 2nd study. The unbalanced pairs are in 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 agent. One becomes attentive to the whole picture, and the eye 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" [14] (p.121). It was found empirically that artist particularly painters had to be used as observers. Painters have been shown to view pictures differently than untrained individuals [10, 21,22, 23,24] . Antes showed that fixation patterns distinguish painters from non-painters, and Koide et al [25] 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. Painters look carefully at pictures for long periods of time so that previous salient aspects are no longer so. In addition, perhaps, artists have an innate disposition to do this.

As noted, polarization destroys the aesthetic effect much more than the effect on eye movement. It would seem that polarized light somehow inhibits the aesthetic feelings associated with the eye movements. To those who equate an aesthetic effect with preference, the aesthetic aspect of this type of balance has not been proven. However, the judgment of preference is a high level cognitive response based on culture and fashion. Geometric forms, strongly contrasting forms or many different equally prominent forms that cannot be combined conceptually force the eye to focus on each particular form. With respect to the latter case, for example, if there is a picture with a distinct mouth in one corner, eyes in another, a chin in a third and so forth, they are seen as distinct salient objects. However, if combined to form a face, they are not likely to be viewed that way. Geometric forms also command the attention and might be interpreted as pictures within the picture. On this level color is never a salient feature. Previously I made a distinct difference between a perfectly balanced picture and all others in order to understand the studies. However, this is not completely applicable to the lived experience where as a picture appears increasingly balanced without these other distracting factors, it will appear increasingly harmonious and unified to those who are sensitive. The state of imbalance will include the geometric or visual state of imbalance as well as these other factors. It is the ability of being able to move smoothly through a painting that determines the degree to which it will seem harmonious and unified.

Normal viewing seems effortless because we are accustomed to the work performed by the eye muscles. However, balance continually exerts a force that differs in each quadrant such that no matter what is being seen, the eye cannot become accustomed to it. No one complains of visual fatigue when intently watching a moving image on an LED screen where balance plays no role, but they do when looking carefully even briefly at pictures. This fatigue seems to limit any study to perhaps 16 pairs or less at a time. The key element is viewing carefully. Casually leafing through a picture book is different.

A flat surface with no marks, i.e. one coated with an opaque layer of paint but gradually modified so that the upper half is slightly darker, also cannot be seen 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 fractal images have an aesthetic quality and that the visual system has evolved to respond to natural conditions [26, 27, 28] . 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 (see comments on Cézanne in addendum A). The author has observed that binocular vision is necessary to observe the percept.

As mentioned above the visual method could be used to solve the problem of balancing non-rectangular pictures that I had only been able to do empirically. This is demonstrated with fig. 3 whose lower half is identical to the balanced fig 4. Both have a luminance of 124.8. 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 has 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. 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) 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

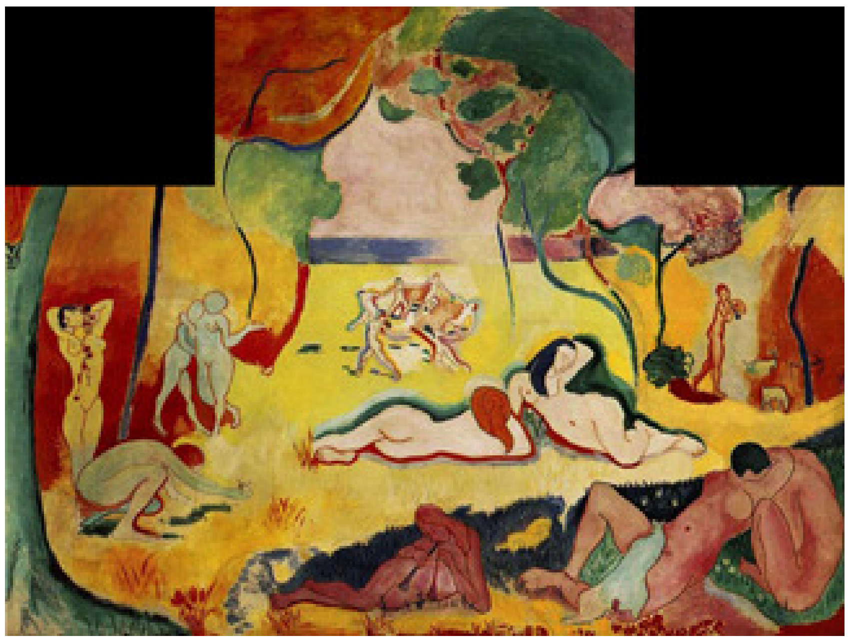

Figure 4 – figure 3 without the obscuring black rectangles

This visual method of following objects using different frequencies might explain to some extent color constancy. One could imagine that this part of the visual system could engage in complex vector and topological analysis of objects as they move and change form.

One can object to the results of this paper as reducing the art of painting to painting by numbers if one were to view pictorial balance as the primary aesthetic objective of painting. Of course, were one to do so, the painting would have to be exhibited under precise conditions and might not look so good otherwise. There has long existed the idea that great art appeals to the intellect and trivializes that which appeals to the senses. At some point that which appeals to the senses arrives to such a level that it achieves an intellectual importance of its own as in "I had never imagined that something like that could exist or be done; it introduces a whole new level of thinking." With art one simply cannot separate one from the other.

Perhaps the most marked characteristic of this aesthetic effect (a really coherent picture)is that the attention is riveted in a powerful involuntary way. This is not contemplation. It is, as Delacroix describes it so eloquently cited below, different from the peak effects of other art forms which can be riveting in their own way - no tearing, shivering or trembling [29, 30, 31] so that how or where a low level response is interpreted on a higher level must be sought elsewhere. An approach to understanding this might be through understanding how polarized light inhibits it.

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

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." [13, 14]

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. 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] (p.68)

Cézanne's comments about painting are most frequently recorded in conversations in which he repeatedly insisted that a painter must paint from nature. However, his paintings are noted 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. I believe Cézanne was attempting to compose balanced pictures that enabled the eye to move through them smoothly as it does when we looked at natural scenes [12]. It would seem that he had no vocabulary to express this other than to say one must paint from nature.

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