Pictorial balance is a bottom-up aesthetic property mediated by eye movements.
A theoretical model of a primitive visual operating system explains 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 upper half less luminous by a factor of 1/(1.07 +/- ~0.03). Two different methods are proposed to calculate balance. A study was done comparing the identical picture in two different frames as to whether they appeared different given that the sole difference was balance. Results show that there was correlation between average pair imbalance and the appearance of difference. Both methods were valid for this population that was selected for their ability to follow the rules and who happened to be mostly painters. Balance affects the ease of making eye movements within a picture and not a force of attraction like saliency. This unaccustomed force causes eye fatigue when pictures are viewed carefully. The second method enables calculations of balance in non-rectangular pictures and explains the riveting of the attention in balanced paintings. The second method enables calculations of balance in non-rectangular pictures. It could be a primitive visual operating system for detecting and following moving objects.

Introduction

Pictures, bounded flat images, 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 4th or 5th 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 bottom up perception of balance: the pathway from the retina to the primary visual cortex as Molnar postulated[3].

But before bottom-up balance is discussed, top-down balance will be reviewed. Colors, form, shapes or tonality have been proposed as contributing to balance. These somewhat immeasurable pictorial qualities are said to be defined as being balanced in a fine picture around a geometric

center using a center-of-mass (CoM) type of equation. It has been stated that as a picture's CoM approaches the geometric center, it will have the aesthetic qualities of pictorial unity and harmony[2,4,5]. There have been many studies that have attempted to show this. However, several authors could not show that this was true in gray scale pictures and Japanese calligraphy[6,7,8]. This is a top-down perception of balance which is a 20th century idea about good pictures. Google ngram studies (which only includes scanned books) using terms such as pictorial balance in English and French show that it was virtually not mentioned before. For example, Rushkin, a major 19th century art critic, does not mention it in his nine fundamental laws of composition although he includes symmetry[8].

In the same way that elements of salience such as color, contrast, and orientation are used to calculate eye movements, one might be able to calculate bottom up balance as a function of pictorial properties. However, the effect of bottom-up balance is not the same as that of salience which determines the next probable eye movement according to a set of scaled salient features and which can be measured using eye tracking[10,11,12]. Low level balance affects the facility of making these movements, the imperceptible effort to move the eye, a much more subtle effect than salience. Normal viewing of the world seems effortless because we are accustomed to the work performed by the eye muscles. However, when viewing a picture carefully, balance continually exerts an inertial force to which the eye is not accustomed. No one complains of visual fatigue when intently watching a moving image on an LED screen or casually paging through a book of pictures where balance plays no role, but they do when looking carefully at pictures.

The only way to measure this obscure force in an absolute manner is to start with a perfectly balanced picture. 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 unnamed effect. It is usually only discussed in art schools when standing before such a picture and then in rather vague terms. 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 perfect balanced and an unbalanced painting that forces the gaze to land on one object and after another object with a decreased feeling of a smooth transition as the picture becomes more unbalanced. I call the percept created by perfect balance 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[13]. Cézanne apparently noted this. Indeed, his inability to describe this effect gives some of his conversations a cryptic quality[14]. Both Delacroix and Kandinsky give vivid descriptions of seeing paintings that exhibit it[15,16,17] (Addendum A).

To study this I created through experience acquired from many years of painting, computer models of pictures that evoke it based on an observation that a painting exhibiting it had to have bilateral luminance symmetry with a slightly darker half 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 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). A perfectly balanced painting will be described as coherent; all others will be called unbalanced for the purpose of the study.

There is a theoretical formula for balance which is derived from this and explains observations of 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). $L_{\mathbf{TOTAL}}$ is taken as the average total luminance.

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

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_{ABQ} 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 the state of perfect balance, it is not clear whether it could be extrapolated to pictorial 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 would have evolved from a primitive method for identifying and following moving objects in a black sea with luminous

other creatures. These 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 vertical gravitational line which is itself bisected horizontally 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 decreased relative to the bottom half by a factor (~1/1.07 in humans) so that a uniform light source would not be seen as balanced. The light energy emanating from each quadrant allows the creation of vectors of luminance permitting the calculation of balance according to the Geometric method. This second method is called the Visual method of balance.

There are two effects conveyed by balance: the intangible effort for the eye to move across the picture and the aesthetic feeling of unity and harmony associated with attention. With a picture seen by reflected light, the two seem inseparable. However an LED picture is a poor conveyer of the aesthetic effect while it maintains the effect on eye movements. The lack of the aesthetic effect in LED pictures is demonstrated by the study of Bertamini et al. who noted that observers preferred a print reproduction to 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[18]. Locher et al. made similar observations[19]. 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[20]. This in some unknown manner interferes with the aesthetic effect or the attention riveting effect so that it cannot be measured using observer preference. LED images had to be used to permit precise luminance determination and reproducibility under the conditions that were feasible,

On one occasion I printed out black and white pictures in which the picture and the frame were of very similar height to length ratios by coincidence so that both the picture and the framed picture were both balanced. Due to an error of alignment some prints did not show the effect. I realized that for the eye the picture included the white frame i.e. at this visual level it could not distinguish between what was picture and what was frame. This is not true for a picture framed in black against a white ground. Since the aesthetic component is not transmitted in LED pictures, a study of observer preference could not be done. However feelings evoked by the ease of movement were experienced allowing a performance based study to determine whether two identical pictures were the same or different where the difference was only the change in balance caused by a change in the frame

The first object of this study is to show that people who follow the rules of the study are able to see this state of perfect balance by showing that they perceive a difference in two identical pictures differing only because one is perfectly balanced. The second objective is to show that the study group is able to distinguish fine degrees of pictorial balance as determined by one or both definitions of pictorial balance (Geometric and Visual).

Materials and Methods

Since a white frame picture is seen by the bottom-up visual system as one object while the top-down view sees it as a picture in an uninteresting frame, this permits the comparison of a balanced picture with the identical picture rendered unbalanced by a slight change of frame. The actual picture is unchanged on the screen pixel by pixel. 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 if the frame was disregarded because I did not think that observers could see degrees of imbalance. Many of the proposed subjects observed the two identical pictures rapidly without close examination and concluded that they saw no difference. These were excluded for not following the rules. Locher and Nagy showed that balance could be detected within 100 msec[21]. However, they were essentially comparing two different pictures with a major pictorial elements shifted around, and the difference could be described. In the present study the comparison is between two identical pictures in every respect. There were a few subjects who did answer instantly and correctly, but most had to take some time, and these were included whether they saw any difference of not. 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 and the other unbalanced (balanced pairs), and five in which both were unbalanced (unbalanced pairs). Images were chosen because they seemed to have predominantly neutral content. Images were prepared using Photoshop©. Quadrant image luminance can be changed in an unobtrusive and precise manner 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. The observer viewed sequentially a picture with different frames on a color-calibrated iPad3 using the ColorTrue™ app and a Colorite™ calibrating 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 5x6.75 inches 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 with accompanying quadrant luminance). They were seen for each subject in this order.

Fig. 1 The three possible image and border combinations where the thick black lines would not be seen on a black ground.

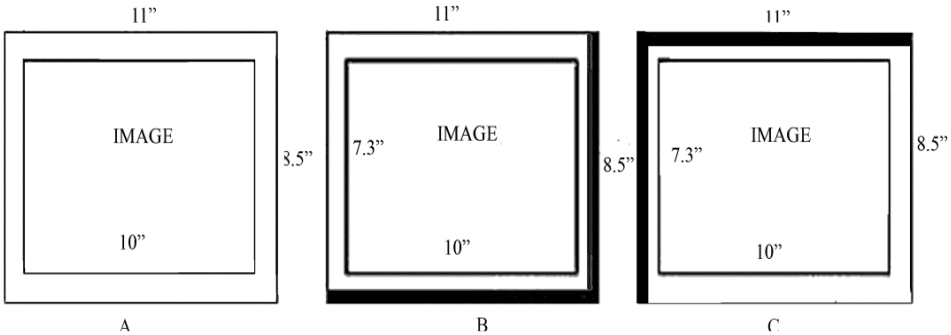

Figure 2 Pictures used in the study pairs

The observers gave their verbal consent to participate in an anonymous study that was about how people look at pictures. They were told that it would consist of looking carefully at ten pairs of pictures while disregarding the frames. They were asked whether the central images appeared to be the same or different and told that it was intended that some pairs might be seen as the same while other pairs 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 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 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 saw differences but could not describe them. These results do not indicate that observers perceived the percept of perfect balance. This is not a very good test for proving that people observer the effect because it is influenced too much by what pictures were chosen as unbalances. Although there are ways to avoid this by having many closely related pictures such as impressionist landscapes that all seem reasonably balanced and then varying them slightly either towards being balanced or unbalanced. I found that you cannot use the same picture twice with one pair being unbalanced and the other pair balanced because observers remember their answers and automatically repeat them. An easier and statistically more powerful way would have been to ask the observers to see how much easier or harder it is to move their eyes around each picture of the pair. I did this with one observer who seemed to have seen the effect in that he identified some of the balanced pairs correctly. He promptly identified all pictures correctly. One could use the test as a screener for subjects who seem to see it and follow up with other pairs that are more closely balanced. (see supplemental files). One cannot due this

at one time because it is very tiring. Furthermore, it is simply not objective to ignore historical and anecdotal evidence in this statistically obsessed society.

Table 1 the number of observers answering correctly

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 found that there is a correlation between the percent of pairs observed as different and the pair average distance (average imbalance) as calculated with these 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: $r(18) = -0.722$, $p < 0.001$. The same correlation for the Visual determination is $r(18) = -0.724$, $p=0.0003$.

If one were to take the average of the balanced pairs as one data point and the ten unbalanced pairs as other data points, The Visual method shows that the correlation is $r(11) = -0.64$ $p= 0.046$. Thus these subjects could perceive relative average balance across the pictures and not just between pairs with low average balance and high average balance. There is no significant correlation with the Geometric method. These methods of determining low level pictorial balance are valid with the Visual method being somewhat more accurate. This method avoids the problem described above in which one is trying to find outliers. Here having a variety of the unbalanced pictures is important.

The ability to see pairs as different as a function of their average imbalance is true for the observers who were selected for their ability to follow the rules and who happened to be mostly painters. I emphasize this because as stated above it cannot usually be seen at first glance. It is possible that if observers were paid to do the study there would be more subjects among the general public who would have been included. As it is these results correlate with studies showing that painters view pictures differently than untrained individuals [21,22,23,24]. 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[25,26].

Table 2 Pair average distance and percent of observers who identified the pairs as different using both the Geometric method and Visual method of balance. The MATLAB™ code used to calculate the Visual balance is in the supplemental files.

	BALANCED PAIRS				UNBALANCED PAIRS			
	Pair	Geometric method distance	Visual Method average distance	% viewed as different	Pair	Geometric method distance	Visual method average distance	% viewed as different
1st Study	1	3.58	8.66	0.49	2	5.69	15.72	0.36
	3	2.50	6.50	0.36	4	14.85	36.18	0.29
	5	3.48	11.06	0.44	6	13.18	30.90	0.33
	7	3.98	8.24	0.38	9	7.44	16.08	0.18
	8	4.04	8.05	0.44	10	17.24	39.02	0.11
2nd Study	1	4.73	11.15	0.41	2	7.33	19.60	0.28
	3	5.07	13.13	0.36	4	16.75	41.25	0.15
	5	3.68	9.92	0.44	6	15.16	29.15	0.38
	7	5.12	13.42	0.28	9	10.81	22.62	0.26
	8	7.98	15.76	0.44	10	19.10	42.68	0.13
Mean		4.42	10.59	0.40		12.75	29.32	0.25
Stdev		1.49	2.88	0.06		4.69	10.35	0.10

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. That observers saw unbalanced pairs as being different was contrary to

expectations, and therefore could not be influenced by the examiner. A MacNemar test showed data validity p < 001.

Observations

Pictorial balance is extremely sensitive to small differences of quadrant luminance which explains its fugacity without precise viewing conditions (table 3). Changing the illuminating 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 make it disappear. Given that not everyone can see the effect which is normally created through chance and even then is usually fleeting, and that there is no name for it, one can understand why it is not discussed in 20th century literature. It is also the reason I wanted to give it the name of pictorial coherence.

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

pair	lateral balance	top/down	pair	lateral balance	top/down
1	1.05	0.97	**6**	**1.04**	**1.37**
	1.00	1.06		**0.97**	**1.23**
2	**1.03**	**0.95**	7	0.94	0.97
	0.99	**1.01**		1.00	1.07
3	1.00	1.06	8	1.00	1.08
	0.93	1.16		**1.10**	1.26
4	**0.98**	**0.90**	**9**	**1.05**	**0.87**
	1.06	**0.83**		**0.98**	**1.01**
5	0.95	1.00	**10**	**0.80**	**0.96**
	1.00	1.07		**0.86**	**1.06**

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[27,28,29]. 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). Uniformly colored geometric forms (no fractal qualities) and many equally prominent forms that cannot be combined conceptually detract from balance. Pair 2 is a good example of this. The eye is forced to go from form to form although as balance improves this becomes slightly easier. Geometric forms are usually solid unvarying color forms that strongly attract the eye.

Balance can be seen as an early evolutionary method to follow a moving object. The Visual method of balance employs imaginary or virtual lines, and the ability to do this in other situations has been demonstrated in vertebrates as primitive as the shark that can see the illusion of kanizsa figures[30,31]. Using balance the visual system would identify the object by this vector and the virtual rectangle. 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. A more balanced living object would imply that you were seen and thus would attract your attention. A perfectly balanced object probably does not exist outside of paintings. In the early evolution of vision in vertebrates, perception information is transmitted by the retinotectal pathway (the superior colliculus in humans) with attention thought to involve the the midbrain where calculations of balance might be located[32].

The Virtual formula also permits the determination of balance in non-rectangular pictures or in those seen at an angle, as well as explains the phenomena sometimes called the Mona Lisa effect. This is where the eyes of a depicted person seem to follow us around the room. The picture is always being viewed as if it were directly in front of us as it literally is with the Visual method[13]. The solution to the calculation of balance which previously could only be done empirically in non-rectangular pictures is demonstrated with fig. 3. The 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 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. 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

In LED pictures there is a decoupling of two low level aesthetic effects. One relates to the ease of making eye movements which is not inhibited while the other rivets the attention in an involuntary way when perfectly balanced and in varying degrees as the picture becomes imbalanced. This is not contemplation. The effect in a coherent picture seen by reflected light is, as so eloquently described by Delacroix cited below, different from the peak effects of other art forms which can be riveting in their own way - no tearing, shivering or trembling so that how or where a low level response is interpreted on a higher level must be sought elsewhere[33,34,35]. Viewing a balanced picture through a polarized filter and comparing the fMRI results with the same picture using a neutral density filter might show where the aesthetic response is located providing you have subjects who can see the effect.

I have rarely seen coherent paintings in museums and when I have, they appeared so from an angle or an inconvenient position. Recently, I found at the Museum of Modern Art in New York a painting by Jackson Pollock entitled *One: Number 31, 195*0 that was coherent as seen at least two months ago. Turning to the left you will see another painting by him in the same style that is not at all coherent. The image found on MoMA's website is good but not coherent.

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."[15,16]

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 full well, that the object [objective form] harms my paintings." [17]

Cézanne's comments about painting are most frequently recorded in conversations in which he repeatedly insisted that a painter must paint from nature[14]. 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[28]. 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. It would seem that he had no vocabulary to express this other than to say one must paint from nature.

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Supplemental Information is available for this paper

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