ARTISTS AND VISION SCIENTISTS CAN LEARN A LOT FROM EACH OTHER, BUT DO THEY?*

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Can science be used to further our understanding of art?
Taylor, Micolich & Jonas (1999)

1. Introduction

Zeki (2002) asserts that visual artists are, in a sense, "neurobiologists of vision, who study the potential and capacity of the visual brain with techniques that are unique to them." The same could, of course, also be said for vision scientists. However, while most artists study vision and perception unwittingly, scientists make it their main objective. A number of papers on art and vision published in highly regarded journals and a stream of conferences on the relationship between visual science and art show that this is a topic of growing interest to the scientific community.[1]

Articles aiming at the contributions of visual science to art and *vice versa* have long been overdue, but were hampered by conceptual incongruencies and differences of language. It is true that artists and vision scientists ask similar questions and study similar phenomena; however, they examine them in different ways. They also pursue different goals. Whereas science is mostly explanatory, art is primarily evocative.

Vision researchers want to explain why we see the way we do, but have only begun to systematically approach objects of art. Their main concern has been with vision and the brain mechanisms underlying the perception of colour, brightness, depth, motion, and form, in response to computer-controlled stimuli, i.e. *bottom up*. In comparison, few artists have exploited the potential of the neurobiology of seeing in their creations. Their aim is to translate their percept of the outer world, such as nature, people, and still lifes onto canvas, which is primarily a *top-down* approach. In their desire to

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* **Dedicated to the memory of Marianne Teuber, 1916-2006, art historian in Arlington, MA.**

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[1] Journals that have published papers on vision and art include *Cerebral Cortex, Nature, Neuron, New England Journal of Medicine, Perception, Science, Trends in Cognitive Sciences, Vision Research,* and *Scientific American*. See also *The Visual Arts and the Natural Sciences in Historical Perspective: An Annotated Bibliography* compiled by David Topper.

depict the world as seen through their eyes and to convey meaning and aesthetic pleasure, they invent and try out ever-new techniques. Creativity, intuition, technique, and the ability to attract an audience are prerequisites for good art; in order to be creative, an artist does not need scientific instruments or books. Imagination is what counts.[2]

Cézanne reportedly once remarked: I do not paint things the way they *look*, but the way I know they *are*. For this reason paintings are often more interesting and richer in their aesthetic appeal than any visual percept that may have prompted them. In comparison, visual phenomena (especially illusions) can serve as non-invasive tools to probe the workings of the brain.[3] Given this dichotomy, Constable's statement that painting is a science … of which pictures are but the experiments can only be taken metaphorically. Obviously, the technique of shading requires knowledge of how to generate relief. The achievement of the relief may then be considered a kind of experiment of how to do it properly. In this sense the process of painting may be regarded as an inquiry into the laws of nature.

Pondering the relationship between art and science, Ramachandran and Hirstein (1999) propose eight principles ("laws") of artistic experience, i.e. rules that artists consciously or unconsciously apply to optimise stimulation of the brain. Some of these rules are drawn from neurobiology, e.g. exaggeration (caricature), distortion (false body proportions), sparse representation (sketch, outline), and peak shift (extraction of the essence). However, only a few of these techniques excite areas in the brain more strongly than happens with natural stimuli, and there is ample evidence suggesting that great art can arise without obeying any of these rules (Mangan 1999).

Following up on his 1999 paper with Hirstein, Ramachandran (2003) poses the question of whether there are artistic universals that cut across cultural divisions. He refers to the above principles (not without adding two), but emphasises that there is a lot of cultural diversity. This implies that art deviates from reality (in the photographic sense), although Renaissance paintings (e.g. trompe l'oeil) are astonishingly accurate (Arnheim 1974; Tyler 2002). On the other hand, artists often maximise a given effect to arrive at a representation that has not been seen before. A cartoon or an outline drawing can be more evocative than the real thing. Picasso's (1923) remark that art is a lie that makes us realize truth comes to mind.

One may argue that art is not so much a matter of distortion, but rather of deliberate emphasis. Artists and draftsmen can choose to emphasise as well as ignore details, while a camera is much more limited requiring a change of depth of field, artificial lighting or pose such as in studio photography, to emphasize detail. For example, anatomical drawings can be more useful than photographs by selecting certain features for better communication. Also, the artist is free to introduce generalities that may transcend individual objects and are common to all of them as a whole. This is easier to do for the painter than the photographer who must rely on a change of viewpoint to enable different interpretations.

[2] Guerri & Huff (2005) note that there was no library at the *Bauhaus* in Dessau, and this "in the land of Gutenberg."

[3] The current popularity of visual illusions (eg *Viperlib*) does not free us from trying to find out how these phenomena come about. The interactive battery of Hans Irtel combining a given phenomenon with parametric variations, a tentative explanation and pertinent references, remains my favourite.

There is another aspect that deserves our interest. In their effort to explore how reality can be most efficiently conveyed on canvas, artists over the centuries have developed techniques that bend the laws of physics without offending the observer's eye (Livingstone 1988; Cavanagh 2005). For example, the direction of lighting and the colour of a shadow may be wrong and there may be colour spilling across the borders; yet these inaccuracies do not seem to matter (Cavanagh 1991). It is this knowledge inherent in paintings that affords insights into the workings of the brain.

2. Perspective

Differences of concepts and language are not the only reason why there is little interaction between artists and scientists; the lack of communication with the other side is another. There are lots of scientists who are interested in art, but as they pursue different goals, they largely confine themselves to their own trade.

Researchers working in perception do not generally refer to the great discoveries made by artists, even in areas where art clearly preceded science. This is because they believe that artists discover something by empirical knowledge, i.e. trial and error, rather than by systematic study. Although this may hold true for many examples, there are notable exceptions. Among them are Alberti, Leonardo and others (e.g. Brunelleschi, della Francesca, Giotto, Masolino, Masaccio) for their deep understanding of perspective, a novel technique that gave the impression of three-dimensionality in early Renaissance paintings long before it became an issue in visual science.[4] Leonardo, of course, was a divine artist as well as a great theorist. He finished only 20 paintings during his lifetime, but spent much of it exploring the arts and sciences and how they could be combined.

The question why a painting that is actually flat looks three-dimensional is perhaps the most profound in all of art (Clausberg 1999). A painting is a painting and not a window to the 3-D world, because of the absence of binocular cues and motion parallax. Yet, although stereopsis tells us that the canvas is two-dimensional, disparity commonly is overridden by cues that afford depth perception even for one eye. Painters never paint a perfect linear perspective, because then the picture would be correct from one position only. Instead they use a modified linear perspective, for which they must have conducted informal visual experiments (e.g. van Gogh's *Bedroom at Arles* 1888). Autostereopsis (Tyler 1979) resulting from regularities of texture is hardly used in art. Such stereograms have been sold many thousands of times as *magic eye patterns*.

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[4] There are numerous and very strong perspective paintings by Duccio, Gaddi, and the Lorenzettis in Italian churches of the fourteenth century, although the perspective is not quite accurate. One of the earliest depictions of perspective in Germany is the painting *Martyrdom of St. Ursula at the City of Cologne* by the Master of the Little Passion (1400-1420). Canvas. Ferdinand Franz Wallraf Collection, Cologne. From about the same time and better known is Masaccio's *Trinità* (1429) in Sta. Maria Novella, Firenze. For detailed discussions of perspective and Renaissance art see Kubovy (1986), Kemp (1990) and Tyler (2000). Worth to be remembered are also the *Chiesa di S. Ignazio* by Pozzi (1543) in Rome and the *Teatro Olimpico* by Palladio (1585) in Vicenza as examples of artistic size-distance illusions. The dramatic change of perceived size in the well-known Ames room was predated by Bernini's misapplied size constancy in the *Scala Regia* of the Vatican Palace by 300 years.

3. Colour Contrast

Perspective is not the only case in point where art led science, colour contrast is another. The fresco of *Madonna del Parto* by Piero della Francesca suggests that he knew about opponent colours. Furthermore, Goethe's *Farbenlehre* (1810), along with Phillip Otto Runge's *Colour sphere*, shows that inferences based on careful observation and intuition anticipated findings made much later by main stream scientists. We know that Goethe's observations influenced the British painter (Joseph Mallord) William Turner (1775-1851), who became interested in visual phenomena such as colour mixture, colour contrast, and colour assimilation. So did the French impressionists Claude Monet, Camille Pisarro, and Henri Matisse after learning about the work of Eugène *Chevreul* (1839), a chemist, on the apparent colour shift in tapestries (Gobelins).

All of this happened prior to the scientific work of such giants in the field as Hermann (von) Helmholtz (1867) and Ewald Hering (1887) on similar topics. Systematic variations in painting were taken up again much later by Paul Klee and Josef Albers, e.g. *Homage to the Square* (1963). Paraphrasing Albers' statement that colour is continuously deceiving, Zakia (2004) remarks: "Colour is a chameleon …. colour does not exist alone, it needs a context, and it needs a background colour." And he continues "Artists can take advantage of this by producing colours beyond the physical constraints of their pigments." [5]

An example is the enhanced glow of the sun (and its reflection on the water) that – paradoxically – was found to be equiluminant with the grey sky in Claude Monet's famous painting *Impression, Soleil Levant* (1872; see Livingstone 2002). In an achromatic photo of the painting the sun disappears and melts into the same grey as the background clouds. Monet's exaggeration of colour contrast is one way of compensating for the restricted intensity range of the canvas (approx. 1:30) compared to that in the real world. High dynamic range is a much-discussed subject matter in graphic arts today.

4. Colour Assimilation

In the wake of the impressionists, the pointillists Georges Seurat, Paul Signac, and Alfred Sisley exploited colour assimilation or *Mixing in the eye* (Ratliff 1992). A good example is Signac's *Papal Palace in Avignon* (1900). One is wondering whether there was any relationship to the Roman church mosaics (e.g. Ravenna) that are based on a similar principle. Both techniques produced perfectly good shapes by placing coloured dots or small square-shaped tiles next to each other without actually using a continuous contour. They may have been prompted by an effort to create vibrant pictures with an air of vagueness (Zimmermann 1991), similar to the dabs and splashes used by Cézanne and the short brush strokes by van Gogh.

Another interpretation is that the pointillists attempted to simulate in their paint-

[5] Delacroix is reported as having remarked: "Give me mud and I will make the skin of Venus out of it, if you will allow me to surround it as I please" (cited in Zakia 2004).

ings the additive colour mixture on the retinal receptor mosaic (Metzger 1936). For example, rather than mixing yellow and blue in their paint, they may have deliberately chosen to place small dots of yellow and blue next to each other to achieve a percept of green in the observer.[6] Cavanagh (2005), advancing a cognitive interpretation, speculates that the amygdala (a centre of emotion in the brain) may respond more strongly to blurry than to sharp scenes thus enhancing the impact of the painting on the onlooker.

Only in the middle of the last century did scientists embark on a more systematic study of colour assimilation (Helson 1963; Jameson & Hurvich 1975). Artists followed, e.g. William Huff and Louis Golomb at the *Hochschule für Gestaltung* in Ulm (Germany). Nowadays, neon colour spreading, watercolour effect, and colour assimilation have become important research topics (Bressan, Mingolla, Spillmann & Watanabe 1997; Pinna, Brelstaff & Spillmann 2001; Monnier & Shevell 2003; Hamburger 2005).

5. Lightness

Next to colour contrast and assimilation, the study of lightness is another case where art preceded science. It took more than 450 years after Leonardo that David Katz (1930), Lájos Kardos (1934), and Wolfgang Metzger (1936, 1954) pointed out the important role of light and shadow for seeing form and space. Every professional photographer makes use of them, but it is only fairly recently that the same observations have been rediscovered in psychophysics (Gilchrist 1994). Visual computation (Hoffman 1998) has greatly contributed by simulating, on a computer monitor, natural phenomena such as light reflection, highlights (gloss), smoothness and roughness, as well as concavity and convexity. Transparency and opacity (Metelli 1974) also belong here. Figure 1 shows a modern rendition of transparency by the painter Hermann Waibel.

Even so, we are far from explaining these percepts neurophysiologically, although they have been widely used in painting (e.g. Lyonel Feininger), map making (shading by contour lines), and in the lighting of sculptures (harsh vs. soft light). Glow was clearly known to the Dutch painters of the 16th and 17th century (e.g. Hals, Rubens, van Dyck, Rembrandt) and has been used as a self-luminous source radiating out in every direction (e.g. *Anbetung der Hirten* by van Honthorst 1590 - 1656). Weale (1985) claims that quite a few of the works by Dutch artists were painted neither *in*, nor *for* daylight. For example, Rembrandt's *nocturnes* convey their mood under subdued lighting better than in daylight, suggesting that he knew about the brightness shift (from green to blue) in dim light, 150 years before the Czech physiologist Jan Evangelista Purkinje described this same effect.

[6] Paradoxically, a pointillistic painting works best at medium distance. It loses essential detail when the elements become perceptually fused and look grey. This is why Signac considered the technique a failure. Metzger (Laws of Seeing, 2006, 40) calls "pointillism a fully unnatural mode of division which one cannot see even with the greatest of effort, but which in perceptual theory has long played an undeserved role." See Figure 11-4 in Vitz & Glimcher (1983) demonstrating optical mixture of the fused dots.

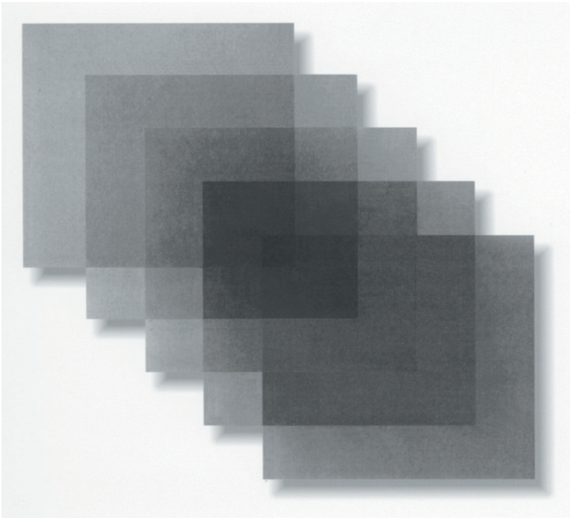

Figure 1: Transparent slabs by Hermann Waibel (2001). Original in shades of red.

Bauhaus teachers advised their students to "open your eyes, become aware of things around you, and describe rather than analyse." In addition, they insisted that textures had to be not only seen, but also felt with eyes closed. Experiencing an object with all the senses was important, as was the combination of physical, sensual, spiritual, and intellectual aspects if ideas were to take the shape of art (Guerri & Huff 2005). Photographers also utilised the laws of seeing. Zakia's (2004) contour tracings (figure 2) represent modern day examples of the Gestalt factors of *similarity* and *good continuation*.

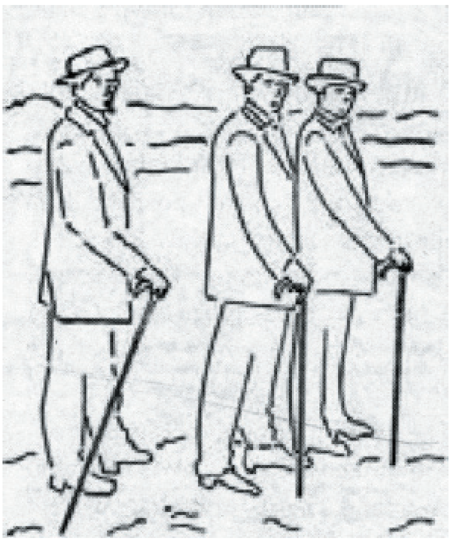

Figure 2: Tracing of a photo by August Sander: *Jungbauern Westerwald,* 1914. Note the similar ity of the two figures on the right vs. the figure on the left. (Courtesy of Richard Zakia)

6. Depth

While artists have tried for 500 years to understand the geometry of perspective and the physics of colour (Kemp 1990), there are other topics where art and visual science could learn from each other. The question of how (non-perspective) depth is represented in a two-dimensional drawing is equally salient (Gombrich 1959). Depth-from-shading to produce depth is present on the *Altar from Osnabrück* (1370-1380), in the engravings of Dürer (1471-1528), and many of the Dutch masters (eg Hendrik Goltzius, 1558-1617), even in excavated Pompeian wall paintings, centuries before depth-from-shading became an issue in visual science. In an example of more recent times, Georges Seurat's *Bathing at Asnières* (1883/4) clearly shows shading at the borders to enhance depth (figure 3).

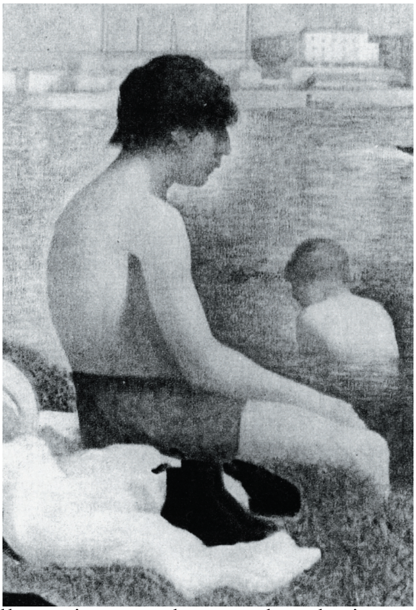

Figure 3: Georges Seurat's *Bathing at Asnières*. Note the volumetric effect arising from bright and dark gradients.

Among the modern painters who were inspired by, and obviously had read, visual science, Salvador Dali stands out. He was well aware of the limitations of the canvas in producing genuine 3-D perceptions and painted a series of large stereoscopic pictures that were displayed by means of mirrors. He is but one painter for whom the interface between vision and art was rather tight.

Depth-from-motion was explored by Marcel Duchamp (1920) in his *rotoreliefs* and – in psychology – by Musatti (1924) in his stereokinetic displays. Escher's ambiguous illustrations can be traced to the impossible objects of the Penroses (1958, see also Teuber 1974, 1986). René Magritte's (1965) well-known rider partially hidden behind the trees derives ambiguity by false depth-from-occlusion.

In op art, Ludwig Wilding's (1975, 1977) striking demonstrations of depth and motion are based on the superposition of a transparent grating onto a background consisting of two gratings with slightly different spatial frequencies. Each of them is folded backward in the middle, like a shallow "V". Depending on the sign of the spatial frequency difference relative to the transparent grating, the superposition results in moiré wedges of opposite depth polarity (Spillmann 1993). As a consequence of retinal disparity, the fringes on the apparently backward-pointing surface appear to move with the observer, whereas on the apparently forward-pointing surface they appear to move in the opposite direction. Motion parallax results in the same percept as is easily confirmed by closing one eye.

In comparison, the motions and plastic deformations perceived in Patrick Hughes' reliefs (*reverspectives*) are due to reversed perspective on surfaces with physical depth. This causes the apparently farther (but actually nearer) surface to move in a direction opposite to the observer, whereas the apparently nearer (but actually farther) surface moves in the same direction (Wade & Hughes 1999). These illusory motion shifts are consistent with what is known about the relationship between head movements and perceived distance. Finally, the hollow (concave) face following us around owes its salience to our tendency to see a face always as convex, even if cues from lighting, texture, and disparity point to the contrary (Gregory 1997). For a hollow pumpkin this does not hold.[7]

Holography, laser photography, and 3D-cinematography are great tools to produce depth. But are they art or just techniques?

Motion

Here we ask about the representation of motion in art. Motion, the strongest visual stimulus of all, is difficult to capture in painting; and yet it has been already attempted early in history (Jung 1990). The use of *axial structures* to depict motion is an ingenious discovery in the arts long before any such approach was undertaken in visual science. Cave painters in Southern France and eastern Spain (Ratliff 1985) as well as Viking voyagers, South African Bushmen, and Australian aborigines used stick figures to depict running men and animals since prehistoric times. Even children immediately recognise such figures as signifying movement.

There are also precedents in sculpture reaching far back into history. Mycenaean Greek processions frescoes (1390 – 1180 BCE) convey the impression of stately movement of human figures in file (Muskett 2005). Another example is the ancient discus thrower (discobolo, 450 BCE).

Motion on canvas emerges much later. Examples include Monet's *Poppy Field outside of Argenteuil* (1873), his *Railroad Bridge at Argenteuil* (1873), and *Rue Montorgueil (*1878). Livingstone (2002) suggests that some of these motion effects may result from the use of near-equiluminant colours. In comparison, Turner's *The Shipwreck* (1805), Renoir's *Dance at Bougival* (1883), and van Gogh's *Wheat Field under Threatening Skies* (1890) use figural elements to achieve the impression of motion.

Cutting (2002) in an article on pictorial cues of motion in art discusses the various techniques used to represent motion on a two-dimensional surface. These are broken symmetry (canting) and multiple "strobed" images as found in high-speed chronographs (e.g. Marey 1882, Muybridge 1887) and painting (Duchamp's *Nude Descending a Staircase* 1912). Affine shear (forward lean), blur (streaking), and action lines (van Gogh's spirals) are others.

More recent examples of motion in art include Dali's demonstrations of figure-ground segregation and motion reversal; the plastic deformation and jazzing present in the works of op-artists Reginald H Neal (*Square of Three* 1965) and Bridget Riley

[7] *Santa Maria presso San Satiro* by Bramante (1478) was the most impressive false depth effect in architecture (see the picture on the web <http://www.arengario.net/momenti/momenti34.html>

(*Descending* 1965-66; *Fall* 1978); the moirés in the vibration structures of Jesus Rafaél Soto (1955-1960), and Wilding's spatial interference patterns; the apparent rotation and counterrotation in Isia Leviant's (1996) *Enigma*; and the striking interactions between colour, motion, and depth in Dorle Wolf's (1999) chromostereoptic paintings.

In vision science, one of the most astonishing demonstrations of motion is *biological motion* (Johansson 1973), as it arises merely from the correlated paths of small light bulbs attached to the main joints of a moving person (i.e. Gestalt factor of *common fate*); a static stimulus will not do. Without any further cues one can instantaneously see a man and a woman engaged in dancing. This percept that also includes depth is closely related to coherent motion perception in optical flow fields (Gibson 1973). Meanwhile, neuronal correlates have been reported for both phenomena (Oram & Perrett 1994; Peterhans, Heider & Baumann 2005).

Biological motion is consistent with the idea that sticks (axes) connect joints and that joint positions define stick orientation (Marr & Nishihara 1978; Kovács 1996). The structural analysis by Arnheim (1974) of the *Creator* reaching out towards Adam in Michelangelo's famous painting is a fascinating application of axial structure towards this masterpiece (figure 4).

Figure 4: Top: Michelangelo's *Creation of Adam,* ca.1510 (Sistine Chapel, Vatican); bottom: Structural analysis by Rudolf Arnheim 1974. Note the aligned arms and the active vs. passive posture of the two figures (courtesy of Giuseppe Galli 2004).

Figure 5 demonstrates floating sensations similar to the so-called Ouchi illusion (Pinna & Spillmann 2005), in a pattern consisting of differently oriented gratings. With a circular motion of the pattern the small rectangle in the middle appears to slide relative to the rectangular frame, which in turn appears to slide relative to the surrounding background. Note that there is also an apparent stratification in depth.

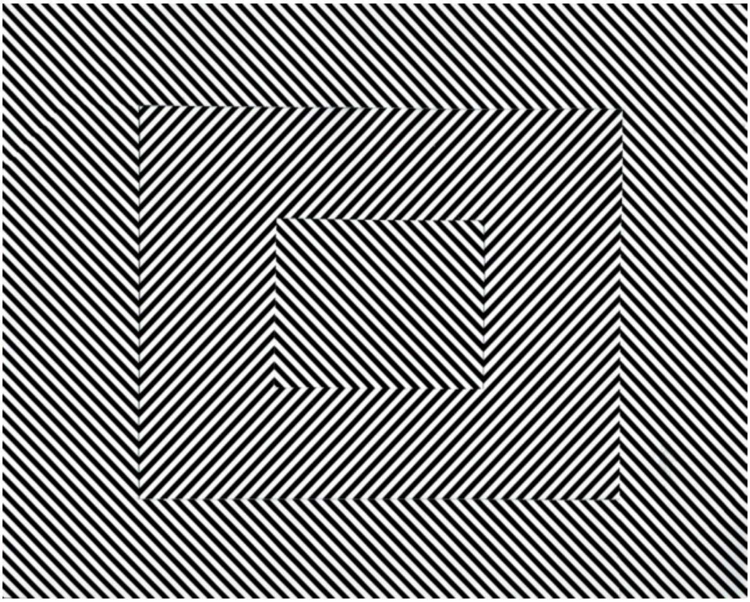

Figure 5: Relative motion elicited by circular movement of the stimulus.

7. Scenes

Compared to visual art, the world of science is typically constrained to the laboratory. Yet, already in 1936, the Gestalt psychologist Wolfgang Metzger applied the *Gesetze des Sehens* (transl. Laws of Seeing, 2006) to nature and the animal kingdom (Thayer & Thayer 1902). Clearly, the visual system developed in response to biological stimuli occurring in our world. This is why cognitive neuroscientists and vision scientists are beginning to realise that simplified, artificial laboratory stimuli such as dots, lines, and gratings are too basic and that important insights may be gained from the study of how we perceive natural, real-world scenes. The study of pre-attentive texture segmentation (Beck 1966; Olson & Attneave 1970) in terms of textons (Julesz 1984) and junctions (Adelson 2000) is nowadays complemented by an approach showing how visual neurones are adapted to the statistics of natural stimuli (Kayser, Körding & König 2004; Körding, Kayser, Einhauser & König 2004).[8] The same issues, of course, arise when we

[8] Pertinent issues include the acquisition of scenes, their layout, the use of spatial scale, the integration of scene information across eye movements, the updating of scenes during movement, the visual search for meaningful objects, scene recognition, scene representation in memory, allocation of attention, eye fixations during scene viewing, and the neural implementation of these representations and processes in the brain. Recent studies of the colour spectra of natural scenes also belong here.

view a painting or photograph of a landscape (figure 6), a portrait or a still life. Thus, by their very nature, such studies should also be relevant to artists.

Figure 6: Perspective depth in a natural setting (courtesy of Michael Wagner)

A constructive interaction between artists and scientists did, in fact, evolve due to practical considerations in the development of wartime camouflage. The military in both world wars engaged the help of experts who applied their knowledge of how to disguise and conceal objects on land and sea from aerial surveillance and U-boat attacks. Many of the strategies adopted rules similar to those that were invented by nature to deceive the eye through false figure-ground organisation (Metzger 1936). Among them are the tearing up of surfaces, the breaking up of contours, and the introduction of deliberately misleading contours. Another purpose, night-time aerial reconnaisance, was served by strobe photography developed by Harold Edgerton at MIT, although nowadays it is better known for the aesthetic pleasure of its "frozen" images. These attempts were to a large extent based on earlier work by Gestaltists such as Kurt Gottschaldt (1926) who had demonstrated that simple geometric figures could be effectively hidden by embedding them in a structurally coherent surround. In art, the surrealist Salvador Dali used multiple hidden images in his paintings to capture his audience, and Bev Doolittle has applied this technique of camouflage to nature in an effort to "slow down the viewing process."

8. Art and Beauty

In the second half of the 20th century many painters and architects no longer strove at harmony and perfection, the elements of beauty. Rather art seemed to be increasingly concerned only with itself. Arnheim's (1969) dictum of "contemporary tendencies in art towards chaos and disorder [as a] degradation of our essential humanity" grew out of this discontent (e.g. deconstructivism). That there was much artistry among chaos has been shown by Taylor, Micolich, and Jonas (1999) who conclude that Jackson Pollock's drip paintings not only mimic nature, but actually invent nature's language – fractals. On the other hand, Levine (2002) asks whether Gestalt theory can do justice to the chaos [and lack of originality] that characterises post-modern art leading to the question whether harmony and perfection in art are at all desirable. Duchamp's (1912) distinction between traditional "retinal art" intended to please the eye, and "grey matter art" designed to put art back in the service of the mind, is an indication of this. The large monochromes by Marc Rothko, one of the foremost representatives of abstract expressionism, may lead in this direction as the uniform colour fields and subtle textures are not meant to be interpreted, but rather to evoke feelings and compassions.

9. Neuronal Mechanisms: Contours

To reiterate Ramachandran (2003), "Art happens in the brain." Surely, there is no visual perception, nor any artistic rendition of the world, that would not be governed by the physiological properties of our eyes and brain. Yet, how relevant are these for a better understanding of art? The example of perspective shows that cognitive processing is at least as important as physiology. Furthermore, the association or meaning one has with a given object in art is as salient as is its form.

Scientific articles relating visual art to its potential brain processes deal with contrast and contours as mediated by oriented line and edge detectors (Jung 1971, 1974; Ratliff 1972). In an illuminating article, Richard Jung (1990) observes that art and vision proceed from opposite directions. He writes "The draughtsman usually first sketches ... linear outlines and later fills them in with hatching or wash to [create] the illusion of light, shade, and plastic form [the fresco technique being a good example]. In vision the eye receives the projections of bright and dark areas on the retina, and the neuronal system codes them for relative brightness and darkness, respectively, and enhances their linear borders [i.e. border contrast]." He continues, "Forms are determined by outlines, … [suggesting] that outlines give sufficient information to characterise a form and that area and colour contrast provide only additional and redundant information."

The reduction of surfaces to contours in drawings can be traced to the early past. Examples are the etching of a bison in limestone, 10,000-15,000 years ago. Note the similarity of the ancient technique with that of a modern drawing (Figs. 7 and 8). The first, of course, looks flat, the second volumetric. Further examples include John Flaxman's (1793) line illustrations of Dante's *Divina Commedia* (see Symmons 1979), where the figure is a mere outline surrounded by a hatched ground; and this happened long before Marr's (1982) concept of a *primal sketch*. In the arts, the emphasis on border may be found in the heavily delineated paintings of Mondrian, Braque, and Beckmann, while the emphasis on surfaces can be found in the colour compositions of Klee, Kandinsky, and Anuszkiewics (see Ratliff and Wurmfeld, 1996).

Figure 7: Bison on limestone, 10,000-15,000 years ago.

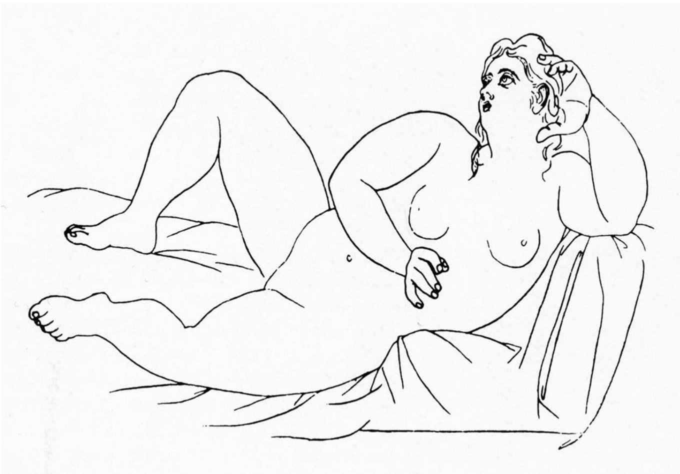

Figure 8: Picasso, *Nu Couché* (1920).

The neurophysiology of the encoding of borders is now fairly well understood in terms of line detectors (for review see Hubel, 1988). A discovery by Baumgartner, von der Heydt, and Peterhans (1984) takes us even further. These researchers demonstrated that neurones in area V2 respond to partially occluded Kanizsa type figures as though they were mediating the illusory contours bridging the gaps in those figures. This finding showed that the visual brain can be creative, enabling us to reconstruct the whole from the parts. The inspiration by the eminent phenomenologist and artist Gaetano Kanizsa (1979) and the ingenuity of the Zurich group thus led to the definition of a globally defined *response field* that takes into account stimulus properties beyond the classically defined *receptive field*.

However, even here there was a precedent in the arts. The American painter Ellsworth Kelly used abutting contours in his illusory staircase painting *La Combe I* as early as 1950. Shapley (1996) offers an excellent analysis of the significance of this painting for the understanding of scene segmentation by neuronal mechanisms that depend on local interactions from fragmentary information. He also found evidence for illusory contours in Indian basket weaving (pers. comm.). Many of the figural constraints that had been proposed for the emergence of illusory contours, e.g. occlusion cues, were thus shown to be unnecessary decades before vision scientists came to the same conclusion.

Continuing along these lines, Susana Martinez-Conde and collaborators (Troncoso, Macknik & Martinez-Conde 2005) recently related the illusory streaks in Vasarely's *Nested Squares* (1969) to antagonistically organised receptive fields in the visual cortex. These authors presented an assembly of cornered brightness gradations to the rhesus monkey while recording from neurones in visual area V1 and found that the neuronal responses to right angles corresponded to the bright streaks seen in Vasarely's painting.

10. Neuronal mechanisms: Surfaces

Borders without surfaces are like skeletons without flesh. We now think that the visual representation of a surface starts with contours and then fills in the enclosed area via long-distance interaction (Spillmann & DeWeerd 2003). This implies that in early vision there is no isomorphic representation in the brain. An example is the *Craik-O'Brien-Cornsweet effect* which elicits perception of two different brightnesses by virtue of a double sawtooth in luminance. Area contrast induced by a luminance gradient was already known to the early Chinese ceramics makers of the Sung dynasty (Ratliff 1972), but it took over a 1000 years to arouse the interest of vision scientists.

A more recent example of surface formation from borders is the watercolour effect by Pinna, Brelstaff & Spillmann (2001). These authors showed that a veil of uniform colour can spread from a chromatic double-contour onto the enclosed area. Even more, the surface not only assumes the colour of the line that borders it, but becomes a figure on the ground, thereby overruling the classical Gestalt factors of *proximity, symmetry, good continuation,* and *closure* (Pinna, Werner & Spillmann 2003; Pinna 2005a). There is no evidence showing that painters (e.g. Kandinsky 1916) were aware of colour spreading (Spillmann & Pinna 2003). However, renaissance mapmakers perhaps knew – and applied – the technique of spreading colour from contours onto surfaces to better separate neighbouring countries from each other (Wollschläger, Rodriguez & Hoffman 2001; Spillmann, Pinna & Werner 2005). There may be a relationship between watercolour spreading and the Renaissance technique of *Chiaroscuro* (Pinna 2005b).

The question of how the watercolour effect combines both uniform coloration and figure-ground segregation and how these effects are related goes back to two important principles pointed out by the Gestalt psychologists (Wertheimer 1923), *uniformity* and *border ownership*. Uniformity stands out as a powerful grouping principle for the formation of extended surfaces. A part of a stimulus pattern that has the same brightness and/or colour thereby becomes a surface in perception.

In addition, it is characterised by a unilateral border, i.e. a contour that delineates, and belongs to, the enclosed surface area (or figure), not the surround (or ground). The unilaterality of a border is enhanced by a gradient in brightness or colour such as in the paintings of Fernand Legér. Few patterns have a bilateral border resulting in figural ambiguity. Figure 9 illustrates figure-ground reversal in an etching by Pierre Crussaire (1774), long before the Danish psychologist Edgar Rubin (1915/21) described rivalry in his vase-face figure.

Figure 9: Etching by Pierre Crussaire: *L'Urne Mysterieuse*, 1774 (Metropolitan Museum, New York City). Section. Note the similarity to Rubin's ambiguous pattern showing vase vs. faces.

Psychophysical, neurophysiological, and computational approaches (Grossberg & Mingolla 1985) have begun to shed light onto the processes that may underlie perceptual segregation based on the spread of brightness and colour from an edge by long-distance filling-in. It is assumed that colour spreading may arise in two steps (Pinna et al 2001): First, by weakening of the contour through lateral inhibition between differentially activated edge cells (local diffusion); and second, by the unhampered flow of colour onto the enclosed area (global diffusion). Edge polarity neurones in visual areas V2 and V4 of the monkey responding to a luminance step in one direction, but not the other, may be responsible for assigning border ownership to a surface (Baumann, van der Zwan & Peterhans 1997; Zhou, Friedman & von der Heydt 2000) and in this way render it unambiguous.

11. Reciprocity Between Art and Science

Although, the relationship between art and science is complementary and both may learn from each other, it is hardly symmetrical. Up to here we have quietly assumed that artists provide the techniques and the phenomena, while scientists propose the explanations. Yet, a closer look suggests that in a number of cases artists seem to have adopted the phenomena from perceptionists. This is not only true in op art (Wade 1978, 1982). The art historian Marianne Teuber (1977) writes in a letter to the author:

> "When you read the Klee paper (Teuber 1976), you will think that Klee was an isolated figure - perhaps the only one who made use of perceptual phenomena. I can show now that a great deal of modern art is actually based on the findings in the field of vision, which were known since Helmholtz and before. … And that is the line I am trying to pursue by starting with Cézanne and going on to Cubism" (cf Teuber 1979; Vitz & Glimcher 1983, 164-167).

We know that the Gestalt psychologist Karl Duncker taught Gestalt psychology at the Bauhaus in Dessau. Furthermore, Josef Albers was aware of Edgar Rubin's (1915) distinction between figure and ground (positive-negative space as it was called), and sketches on form and transparency in Paul Klee's (1957) pedagogic diaries contain notions reminiscent of the work by Max Wertheimer (1923) and Ernst Mach. Indeed, Klee refers to Mach's (1900) *Analysis of Sensations*. Fechner's (1876) *Vorschule der Ästhetik* and his work on the *golden section* most certainly was known to members of the *Bauhaus*, suggesting that psychologists there may have inspired artists as often as the other way round. Teuber (1982) writes that Picasso discussed William James' *Principles of Psychology* with Gertrude Stein; and Stein showed Picasso Mach's folded card illusion, a reversible figure that may have given birth to analytic cubism.

However, Teuber's suggestion that in our times science often took priority over art may not generally hold true. In their book, Vitz and Glimcher (1983) point out striking parallels in art and perception, but they fail to demonstrate a direct, causal influence of one on the other (Wertheimer & Werner 1984).

12. Interactions Between Artists and Scientists

This brings us to the question of how we can promote a more productive interaction between visual artists and scientists. The scientific study of vision relevant to art includes articles on eye and head position in portraits (Grüsser, Selke & Zynda 1988; Tyler 1998), representations of depth curvature on the body surface (Koenderink 1984, 1998), apparent rotary motion in the Enigma figure (Zeki, Watson & Frackowiak 1993), light and shadow to disambiguate depth (Sun & Perona 1998), and symmetry and perspective in paintings (Tyler 1998, 2000). The *Venus* effect (Bertamini, Latto & Spooner 2003), the effect of hemispheric laterality (Vogt & Magnussen 2005), and the structural analysis of facial expression, i.e. Mona Lisa's mysterious smile (Livingstone 2000; Kontsevitch & Tyler 2004) are further examples by scientists to understand topics exploited in art.

Werner (1998) offers a rare in-depth analysis of the effect of crystalline lens turbidity (cataract) on the painting of Claude Monet; and an essay by Jung (1977) on lateralisation in left-handed artists from Leonardo to Klee is equally revealing. Both articles show the close relationship between art, psychophysics, and neurology. Livingstone and Conway (2004), provide evidence that Rembrandt suffered from divergent strabism in one eye. Trevor-Roper's (1970) *World Through Blunted Sight* and *The Eye of the Artist* by Marmor and Ravin (1997) also belong here, showing the effects of defective vision in the eye (e.g. short- and far-sightedness, colour deficiency, cataract, etc.) on art. Clausberg's (1999) *Neuronale Kunstgeschichte* adds examples of the impact of impaired processing in the visual brain. A well-known case is that of the painter Anton Räderscheidt who exhibited a hemineglect syndrome after a stroke and as a result portrayed only the left side of his face, with partial recovery in the course of 1 year (Jung 1974). Thus, although great and inspiring treatises on art and vision and art and neurophysiology have been written, more is yet to be learnt.[9]

13. Incongruencies

Why then are there so few artists interested in discussing science? Meetings at which both artists and visual scientists are present show that the languages spoken by the two camps are different and the concepts are not mutually understandable. Ilona Kovács (pers. comm.) concludes: "Artists are not good at trying to be scientists and scientists are not good at trying to be artists."

One may ask why should they? Wade (2003) mentions op-artist Bridget Riley as being "renowned for her scorn of optical analyses of her work" and notes a "fundamental difference in approach between science and art, even when dealing with the same phenomena." He continues: "Artists enhance and elaborate those effects, whereas scientists contract and constrain them." Scientists must support their claims by experimental evidence and stringent reasoning. Their results must be novel, reproducible, and consistent with extant knowledge. They typically work in teams and take a long time to perform an experiment and even longer to write it up. Will scientists benefit from knowing about painting?

In comparison, artists are their own geniuses capable of finishing a painting in one day, although some artists are renowned for spending years on the same painting, e.g. Leonardo on the *Last Supper*. At the same time artists often work on variations of the same (e.g. Cézanne's eighty-seven paintings of *Montagne Sainte-Victoire;* Monet's paintings of the Rouen cathedral under different lighting) and need not worry about originality and novelty, nor do they need to understand the mechanisms of vision. Their yardstick for innovation is not so much the *what*, but the *how*.

This is best exemplified by Roy Lichtenstein's *Rouen Cathedral Set V* (1969), a reflection on Monet's series of impressionistic paintings (Tyler 2005). The three panels differ only in colour. While the left and right panels are painted in bold shades, the central panel consists of equiluminant reds and greens eliciting a vibrant haze. Tyler argues that although the colours are subtle, they are readily seen, presumably by the *parvo- or What-system*. In comparison, the forms seem to shimmer and convey little depth. This may be because the *magno-* or *Where*-system in the brain is not properly activated by the pure colour differences and therefore signals poorly defined shape and position as is well known from psychophysics (Liebmann 1927; Gregory & Heard 1979; Livingstone 2002).

[9] Books on art and vision include Kepes 1949; Arnheim 1954/74; 1966; Gombrich 1959; Albers 1963, 1969; Carraher & Thurston 1966; Pirenne 1970; Gregory & Gombrich 1973; Vitz & Glimcher 1983; Solso 1994; Gregory, Harris, Heard & Rose 1995; Ninio 1998; Parovel 2004. Books on art and neuroscience include Maffei & Fiorentini 1995; Clausberg 1999; Zeki 1999; Livingstone 2002.

This difference in aim between art and science is captured by Anthony Freeman's (Managing Editor of *Consciousness Studies*) remark: Paradoxically, the scientist reveals the truth by coming up with consistently identical results, while the artist reveals truth by coming up with consistently different results. Picasso once remarked: If there were only one truth, you couldn't paint a hundred canvases on the same theme. Painters are using for their paintings the same eyes whose function scientists are trying to understand. But will they benefit from knowing about the brain mechanisms underlying vision and perception? Their success depends profoundly on the judgement of an audience and professional art critics, whereas the success of scientists depends on peer reviews and subsequent citations. Both are subject to the *Zeitgeist*.

After the closure of the *New Bauhaus* (1968) in Ulm, a forum where scientific results, widely divergent ideas, and experiences from different domains of art and visual science were equally shared, no institution quite like it has emerged in Europe. On the other hand, the success of *Yaddo*, the famous artists' retreat and working community in Saratoga, Upstate New York, with academicians, artists, and scientists in residence, shows that rich cross-fertilisation can still occur.[10]

14. Neuroimaging

For some time now there has been a move in the art world (and scientific world as well) to scan peoples' brains in an attempt to find out what responses are evoked by different kinds of paintings (see recent issues of *Leonardo*). What is actually learnt here? We now know that bilateral lesions to the face area will produce face blindness (Kanwisher, McDermott & Chun 1997). As in the case of *prosopagnosia*, one therefore might ask which area – if any - in the brain is active when one looks at a piece of art. Patient W.L., faceblind after a stroke, complained that when he was able to recognise his own paintings, they appeared to be foreign, lacking the personal relationship a painter typically has to his paintings (Spillmann et al 2000). The question then arises whether there is a brain-module (Marshall 1989; Ramachandran 2003) for the aesthetic sense, i.e. a brain area specifically dedicated to art. This would be the area artists would want to address if they intend to evoke a certain mood in the onlooker (e.g. the loneliness in the paintings of Edward Hopper).

Kawabata and Zeki (2004) applied brain-imaging techniques using a portrait, a landscape, a still life, and an abstract composition as stimuli. They found that irrespective of the different categories of paintings, the orbito-frontal cortex was differentially engaged when beautiful vs. ugly stimuli were presented. An fMRI study by Jacobsen, Schubotz, Hofel and Cramon (2006) similarly showed that judgments of "beautiful" are accompanied by enhanced BOLD (blood-oxygen-level-dependent) signals in the frontomedial as well as the intraparietal cortex.

[10] Among those who embrace both art and visual science are Gaetano Kanizsa, Jacques Ninio, Giulia Parovel, Baingio Pinna, Nick Wade, Dorle and Rainer Wolf, and the vision scientists and art collectors Georg von Békésy, Richard Jung, Floyd Ratliff, and Henk van der Tweel.

A further question is whether paintings, photographs, and real objects each stimulate different populations of neurones. Using a wide variety of pictures from abstract, Impressionistic, and Post-impressionistic art as well as photographs of landscapes, artifacts, and urban scenes, Cela-Conde et al (2004) found that the prefrontal dorsolateral area was selectively activated in human magnetoencephalograms during the perception of objects judged beautiful. This then may be a hypothetical brain site for aesthetics, although the idea of a brain module for aesthetic quality may be untenable, as the concept changes with history, culture and, social class. The same *caveat* applies to the Visual Aesthetic Sensitivity Test (VAST) developed by Karl Otto Götz. Why should we assume that nature designed our brains for the purpose of admiring a painting? To speak with Desmond Morris (1962), is our appreciation of art profoundly different from that of apes - or is art a human domain? (See figure 10)

Figure 10: Cat Zia looking at a painting by Paul Klee (Courtesy of Ernst Peterhans)

15. Eye Movements and Attention

So far we have largely ignored the role of eye movements in the viewing of artwork. To view a scene in a painting, saccades must move the fovea to the area of interest. The choice of a saccadic landing place may depend either on passive attention attracted by the stimulus, on active attention pertinent to the task, or a combination of both. The Russian physiologist Alfred Yarbus (1967) analysed the eye movements of a subject who viewed a painting and noted that foveation was contingent on the stimulus features having the greatest salience. This suggests that eye movements were predominantly stimulus-driven, i.e. bottom-up. In comparison, Robert Solso (1994) reports that eye movements during viewing of a painting depend also on the instruction, i.e. top-down. Given these two alternatives, can we tell from eye movement patterns the cues for beauty and aesthetic appearance? Ocular scan paths would be expected to differ among individuals depending on interest, expertise, and attention to stimulus features (Vogt & Magnussen 2007).

How the hand and brain interact in the drawing of a portrait was recently documented and analysed by Miall and Tchalenko (2001), who collaborated with a professional painter. They precisely recorded eye and hand movement to find out how the eye captures a painting, the brain processes it, the hand implements it, and the eye evaluates it in eye-brain-hand-eye cycles, each lasting a few seconds or less. Brain imaging during the drawing of a portrait revealed activation in the frontal regions, suggesting "that the painter was relying on an abstracted representation. He was 'thinking' the portraits." In contrast, the non-artists showed most activation in the posterior region of the visual cortex, indicating that "they were 'slavishly copying' the photograph." The fovea plays a great role in both strategies because of its superior visual acuity. This superiority was captured by the Italian sculptor Medardo Rosso (1858-1928) who – in photographs of his works – represented the central area of the visual field in sharp focus and the peripheral area progressively blurred (Melcher & Bacci 2003; see figure 3 in Wade 2003).

16. Aesthetics

In 1876, the eminent mathematician Charles Henry influenced by Fechner's *Elemente der Psychophysik* (1860) and influential on Seurat (see Homer 1964), founded an academic discipline called *experimental aesthetics* (Arguelles 1972; Zimmermann 1991). It was soon to be followed by the respected *Zeitschrift für experimentelle Aesthetik*. In 1935, the Japanese psychologist S. Morinaga studied experimentally, how Gestalt rules govern aesthetic arrangements. Thirty years later, Metzger (1966) argued that perceptual (Gestalt) laws also concern aesthetic properties and, *vice versa*, geometrical shapes convey meaning and expression. He proposed that "meaning exists in the perceived structure" (cf Shigeko Takahashi, 1995).[11]

In recent years, Latto, Brain & Kelly (2000) studied the effect of the orientation of Mondrian's paintings on their aesthetic appeal. They found a stronger preference for pictures with their component lines oriented parallel to the frame (i.e. horizontal/vertical) rather than pictures with their component lines oriented obliquely. They concluded that we find pleasing those stimuli that are closely tuned to the properties of the human visual system (Appelle 1972). Could Mondrian have known about this?

Thus, although it is true that artists who exploit the potential of the visual brain in their creations provide a rich resource to visual scientists (Zeki 2002), their merit to

[11] An important line of study called *New experimental aesthetics* is associated with the name of D. E. Berlyne (1971), who used magnitude estimation and factor analysis to quantify art along dimensions such as arousal, pleasure, hedonic value, balance, and proportion. This school is organised in the *International Association of Empirical Aesthetics* and has a magazine called *Empirical Studies of the Arts*. In Europe, Rentschler, Epstein and Herzberger (1988) published a book on *Beauty and the Brain. Biological aspects of aesthetics*.

the visual science side remains yet to be fully appreciated. A greater interaction between artists and scientists to discuss vision and visual experience is sorely needed and would benefit either side. Now since the important questions of depth, colour, lightness, and motion have been tackled and their relationships to the underlying brain mechanisms thrown wide open (Clausberg 1999; Werner & Ratliff 1999; Livingstone 2002), more specific questions await our attention.

17. Outlook

This article was prompted by a desire to incite a more vigorous discussion between artists and visual scientists for the benefit of either side. For the scientist the question arises as to what can and cannot be tested empirically. Brain imaging techniques can tell us about cerebral localisation. Using positron emission tomography, Zeki, Watson & Frackowiak (1993) found activation in motion-sensitive cortical areas in response to Leviant's *Enigma,* a figure eliciting apparent rotary motion in the absence of real motion. This finding suggests that the same neural mechanisms that also mediate perception of real motion are also responsible for the Enigma illusion. Studies like this one may eventually help us to better understand where a given effect arises and whether it is art or artefact.

Zusammenfassung

Künstler und Sehforscher verfolgen verwandte Fragestellungen, sprechen aber selten miteinander. Die Beziehung zwischen den beiden Lagern wird untersucht, und die Beschäftigung mit Themen wie Perspektive, Farbe, Helligkeit, Tiefe und Bewegung wird aus der Sicht jeder dieser beiden Gruppen dargestellt. Der Artikel zeigt, wie Entdeckungen auf dem Gebiet der Kunst denen auf dem Gebiet der Wissenschaft in vielen Fällen vorausgegangen sind, es gibt aber genügend gegenteilige Beispiele, besonders auf dem Gebiet der Op-Art. Das Studium der Farbassimilation und natürlicher Szenen könnte einen Dialog eröffnen, der bisher nur selten stattgefunden hat. Von einer Wechselwirkung zwischen Kunst und Wissenschaft hätten beide Lager einen Gewinn.

Summary

Artists and vision scientists work on related topics, but seldom interact. The relationship between the two is examined and their occupation with topics such as perspective, colour, lightness, depth, and motion is shown from the side of each of these two camps. It is shown how discoveries in art preceded those in science in many instances, but there are examples to the contrary, especially in op art. The study of colour assimilation and natural scenes may start a dialogue that up to now has rarely happened. Interaction between art and science would benefit both.

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