CHAPTER 19

PICTORIAL CUES IN ART AND IN VISUAL PERCEPTION

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Introduction: why do we look at pictures?

Artists have been looking at the world for thousands of years, and thus paintings and drawings can be considered to form a 40 000-year-old corpus of experimental psychology of perception. Through observation and trial-and-error they have exploited the principles of how our brains interpret the input from the retina, giving priority to only certain regularities of the visual pattern. Thus, a study of pictorial cues can tell us about the way that the brain recognizes objects, understands spatial depth, and uses illumination information in natural environments. Conversely, a better understanding of visual perception may help to explain the effectiveness of certain techniques used by artists. Therefore this essay will focus on some basic techniques in pictorial depiction that allow blobs of paint or charcoal marks to evoke objects, depth, movement, transparency, illumination, and reflection. The development of these pictorial techniques by artists can be considered as fundamental discoveries about the neuroscience of perception.

The human eye responds to a limited range of frequencies of electromagnetic radiation known as visible light. This light is focused by the lens of the eye and then, via special cells in the retina, translated into a pattern of neural firing that is sent to the brain. The brain's dedicated network for making sense of the pattern of light evolved to respond to dynamic, three-dimensional environments, but even a flat, static image can provide enough cues to trigger the recognition of objects and scenes. These flat pictures do not behave like three-dimensional objects and scenes, nor do they change with self-movement like reflections in water or a mirror. Instead, the projection of a flat picture on the retina is deformed when the viewing point of the observer changes, a fact which is made apparent in photographs of photographs or photographs of a flat object which has been folded or rotated (Fig. 19.1). Across various cultures (Kennedy and Ross 1975) and even in some animals (Itakura 1994), there is a surprising tolerance to flatness

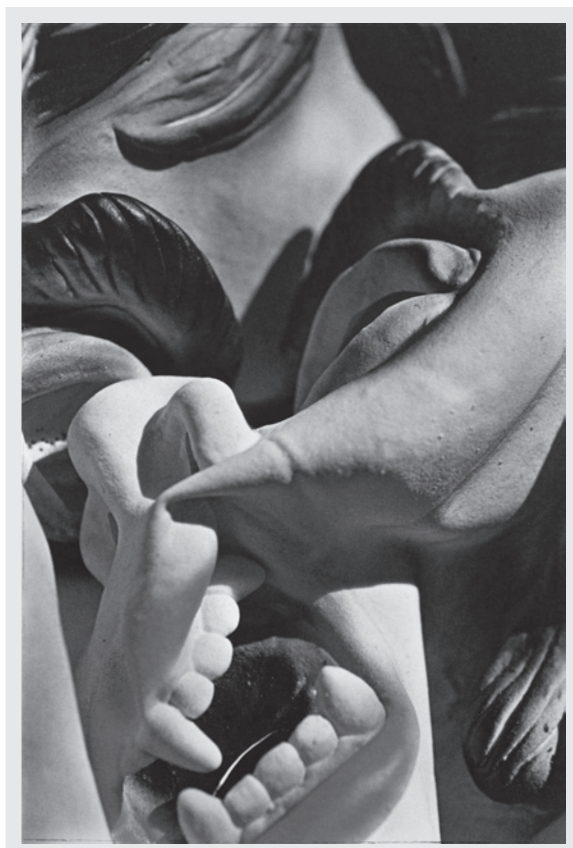

Fig. 19.1 Cindy Sherman, *Untitled n. 246*, 1987–91.

(Mart Museum, *Rovereto*)

The visual system is incredibly adept at reconstructing from a photograph the flatness of objects such as a photograph or even a rubber mask. However, a photograph of a folded, crumpled or bent image no longer supports the percept of the veridical shape of the image. In this case, a simple rubber mask that is twisted and folded takes on a distorted, almost horrific, appearance.

and stasis in images: this relative insensitivity to the dramatic difference between a picture and the real world is one of the foundations of visual art. In fact, it is difficult to image modern life without this ability to overcome the lack of three-dimensionality in pictures. A world without tolerance to flatness would contain no paintings, posters, televisions, or cinema but would instead be filled with statues of people and sculptures of scenes, in place of pictures and photographs.

This essay will focus on the techniques used by artists to depict recognizable objects and scenes in flat representations. Of particular interest is the many ways in which pictures deviate from 'correct' optical representations. Our visual system has a lifetime of experience with real scenes, but the same brain is able to make sense of pictures which, in many ways, look nothing like optically produced images.

For example, the style of film-making known as the 'Hollywood style', which has developed over the past century (Bordwell et al. 1985) aims to shoot and edit the scenes in such a way that the lighting, placement, and use of cameras, set design, and editing is not noticed by the viewer (Reisz and Miller 1968; Bordwell et al. 1985; Cutting 2005). This focused approach to narrative film-making does not attract attention to the process itself, but rather the story. The principles that allow for seamless perception of such an artificial medium are critical for understanding the mind. In order to go unnoticed, film techniques must work within the constraints of the human visual system. Thus, movies can tell us something also about how we perceive the real world, even if the scene in question (such as a flying superhero) could not exist in everyday life. Similarly, artists working with static media such as photography, drawing, or painting can choose to portray pictorial information—such as object shape and colour, lighting, depth, and reflection—rather than drawing attention to their technique itself. It is useful to investigate the nature of pictorial cues that maximize the ability to recognize objects and scenes in order to better appreciate the deviations from these rules. It is this ability of art to reproduce certain aspects of natural scenes without merely copying them that provides insight into the workings of the human perceptual system: an understanding of 'psychophysics' of the brain rather than the physics of optics.

Depicting object contours

One common attribute of pictures in a broad array of artistic traditions, starting from the earliest surviving depictions on cave walls, is the use of boundary lines to depict the edges of objects. Of course there are no actual contour lines dividing real objects from their backgrounds in most cases, which raises the question of why contour lines are so ubiquitous and effective in depiction. One theory is that line drawings are a convention that are imposed within a particular culture and passed down through learning. The fact that some animals (Itakura 1994), human infants

(Yonas and Arterberry 1994), and members of stone-age tribes (Kennedy and Ross 1975) have all been shown to interpret line drawings as objects argues strongly against this idea.

It is clear that boundary lines are important to the brain. The initial stages of visual processing focus on finding discontinuities in brightness, colour, and depth, a scientific discovery which led to the awarding of the 1981 Nobel Prize to Torsten Wiesel and David Hubel. Some of these discontinuities capture important information about the objects and surfaces in a scene, but many are accidental and uninformative. Artists making a line drawing usually focus on the most important of these transitions in brightness, colour, and depth, leaving out the edges of cast shadows and transitions in colours. In particular, contours are used to represent three-dimensional shapes. This is true both from a developmental perspective, as is apparent from looking at children's pictures, and from an art historical point of view—considering that the artists' training has traditionally included sketching from life as one of the most important exercises. When an artist is able to depict the form of an object, this signifies an understanding (implicit or explicit) of the key contours that must be extracted by the visual system in the brain in order to recognize the three-dimensional structure of a particular object. The process of drawing is essentially a process of selection. Extracting all lines from an image would create a confusing mess which lacks the economy of a child's drawing or the poetry of an artist's sketch (Fig. 19.2). The neuroscientists of the Palaeolithic era discovered the essentials of the principles of shape-by-contour, the rules of which are still being investigated by scientists of the twenty-first century. As such, artworks can be viewed as scientific data: perhaps by studying the use of lines by artists, scientists may learn the explicit rules of this implicit, secret knowledge.

Boundaries are critically important not just for vision but also for haptics, understanding objects through touch. Lines perceived through the eyes can support the recognition of objects that have only been experienced through touch. One of the most

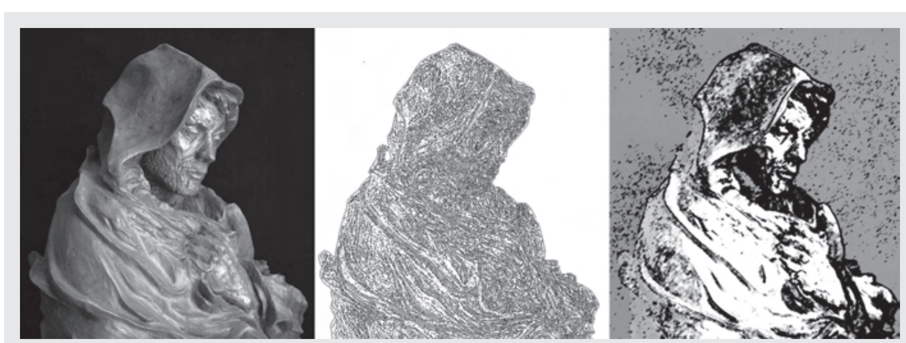

Fig. 19.2 Photograph of the sculpture 'Saint Francis as Brother Wind' by Fiorenzo Bacci (San Damiano, Assisi), a version of the same modified using the 'extract contour' function of Photoshop, a version of the same using the 'sketch/chalk and charcoal effect' function of Photoshop.

(photograph by Nicola De Pisapia and modified versions by Francesca Bacci) striking examples of this multisensory representation of objects is the case of Sidney Bradford, who acquired vision at age 56 after a life of blindness (Gregory 2004). The vision scientist Richard Gregory interviewed him shortly after the surgery, but suspected a hoax when the patient immediately read the time of the clock on the wall. It turned out that Bradford could visually recognize all objects—and only those objects—that he had previously recognized through touch (see Bacci, Chapter 7, this volume). The similarity between identifying an object by seeing its drawn contours and feeling the contours with the eyes closed has been confirmed in several studies using neuroimaging (see Amedi et al., Chapter 23, this volume). Indeed, there are many blind artists that can create images on flat surfaces that capture their experience of objects they have only touched and are interpretable to the sighted.

Moreover, there are various lines of evidence to show that viewing the outline drawing of a tool can lead to activation in the brain's regions involved in planning grasping movements, even if there is no motor response required for the task (for example, Chao and Martin 2000; Devlin et al. 2002). One line of experimental evidence involves 'affordance' effects, such as the finding that we are quicker to press a button with our right hand when responding to a photograph of a cup whose handle is oriented towards the right (Craighero et al. 1998; Tucker and Ellis 1998). The priming of action by the right hand, in that experiment, occurs even though the stimulus is a photograph and the observer is making a judgement about the name, not the shape, of the object. Some patients with damage to a specific area of their frontal lobes develop a disorder known as 'utilization behaviour' (Lhermitte 1983). If you place a cup in front of the patient, s/he will pick it up and attempt to drink out of it. If the patient sees eyeglasses, he or she will immediately put them on, even if already wearing another pair. The patient cannot resist a bowl of fruit, they feel that the object 'orders' them to use it.[1]

Overall, research suggests that artworks, even simple line drawings, have the potential of evoking a visual-motor response. This raises the empirical question of which artworks engage the observer's brain in this way and why. Drawings by the artist Claude Heath (see Bacci, Chapter 7, this volume) provide an interesting starting point for discussing the meaning of drawn contours. Heath has drawn objects while blindfolded, using only the sense of touch. He places a small point of reference, such as a piece of Blu-Tack, on the object and another on the piece of paper. Subsequently, he explores the object with one hand while simultaneously drawing with the other, being careful to maintain exactly the same distance from the reference points in both of his hand journeys. This exercise reminds us that drawings tend to use lines which are not real—the contour simply gives the useful information about where the object ceases to 'spread out' in relation to the centre of our gaze at that moment. Movement by the

[1] Interestingly, a recent study of obesity suggests that food also tempts our hands as soon as we see it (Myslobodsky, 2003). According to the Stoics, the perception of an object was automatically tied up with its ability to create an impulse towards or away that object (*phantasia hormetikê*). Similarly, phenomenological philosophy has stressed the 'embodied' nature of humans within an environment full of objects that are 'at-hand' and suggest action. Recent work in the study of vision is beginning to reveal these links between vision, the other senses and the body.

observer or the object changes the project of this contour in two dimensions. For our visual system, this 'viewpoint specific' representation of shape is useful, but our brain also appears to calculate an estimate of the 'unseen', real three-dimensional shape of the object. Why? Because visual contours are not interesting, per se, for actions such as grasping, which are based on where to put the hand in relation to the three-dimensional shape of the object. These 'touch contours' are not viewpoint-specific. When you reach to grab a cup, or to embrace a lover, your grasp extends around into the unseen, but 'perceived' limits of the body. When Heath closes his eyes and draws what he feels with his hands, he may be trying to access the information that we use for action. Interestingly, the artist uses Blu-Tack to anchor his hand at a fixed point on the paper. Does this mean that he is using a hand-centred representation of space with his drawing hand to draw what he is perceiving with his other, feeling hand? The shape of the lines suggests a three-dimensionality that is difficult to translate into the contour-based medium of drawing. That may be one reason why Heath's drawings are so intriguing.

Two pathways to object recognition

When it comes to recognizing objects, boundary lines are certainly not the whole story. Let's take a moment to look at how we see. At the centre of our gaze, the world appears in fine detail and in colour, while the percept from the peripheral areas of our field of vision yields less precise information. Central vision is useful for tasks like reading and guiding complicated actions, while peripheral information gives a more general idea of the identity of an object and whether or not it is moving. Because visual acuity is best at the centre of gaze (the fovea), most people look directly at objects of interest. Nonetheless, it is clear that we are able to understand a great deal about the world even out of the corner of the eye or in a dimly lit room where the 'fine detail' pathway is of little use.

One reason that coarse information might be particularly useful is time. There are fundamental constraints on how biological systems can encode and extract information over time. With our big, energy-consuming brains processing all of these minute, fine details, the whole process can get pretty slow. Thus, it seems that in addition to the 'fine detail' pathway there is also a visual 'fast track' that can begin more quickly to influence behaviour based on the coarse pattern without waiting for the exact details to arrive. Presumably, this design allows for quick responses to salient events, such as the arrival of a speeding bus or the presence of a rattlesnake in the hiking path.

Using sophisticated laboratory techniques, it is possible to measure the processing of coarse visual information. One finding from these studies is that certain patterns evoke emotional responses and that it is the coarse information that plays the predominant role (for review, see Vuilleumier and Pourtois 2007). In fact, this coarse information can affect our responses even to stimuli that we do not really see, when they are presented in the laboratory under conditions in which the stimulus does not reach conscious awareness.

Thus, artists have at their disposal at least two routes to visual recognition: the slow, detailed pathway and the fast but coarse pathway. Face recognition, for example, does not depend on seeing local details or even the presence of eyes, nose, and mouth in the depiction. The right pattern of light and dark patches is sufficient to evoke face recognition in the brain. In fact, people are surprisingly adept at seeing faces or animals in random patterns like clouds. At night, our ancestors played a similar game with the stars: when, connecting mentally the celestial dots, archers, or bears appeared before their eyes. On a clear night, even the man on the moon shows his face. Leonardo saw this capacity as the basis of artistic creativity and recommended to his students to stare at natural patterns and try to find people, animals, and scenes hidden inside.

Giovan Battista Alberti noted that 'nature herself seems to delight in painting, for in the cut faces of marble she often paints centaurs and faces of bearded and curly headed kings' (*Della Pittura*, Book II, 28 [author's translation]). People flock to see such miracles of nature, particularly when the subject matter is religious. Recent examples include an appearance by the Virgin Mary on a tortilla, which drew tens of thousands of pilgrims, or her miraculous appearance on a toasted cheese sandwich, which sold on eBay for an incredible US $28 000. Likewise, the devil has appeared on the Canadian dollar bill and in a smoke pattern on the CNN news channel (smoke, like clouds, is a common medium for this phenomenon).

The fact that people tend to see people or animals in naturally occurring patterns is called *pareidolia* (from the Greek *para* (beyond, over) and *eidolon* (image, percept)). The fact that pareidolia tends to involve animals and faces may be related to the way that the visual system quickly and automatically identifies those stimuli (Melcher and Bacci 2008). 'Rapid visual categorization' is the term given by scientists to describe the ability of people in a laboratory setting to discriminate whether or not an animal is present in a picture (Thorpe et al. 1996; Rousselet et al. 2002). This ability appears to be largely automatic, since it requires little or no focused attention and occurs even for stimuli viewed out of the corner of the eye. Rapid categorization seems to work particularly well with animals and people. Moreover, a number of studies have shown that faces in particular can be detected quickly: our brain appears hardwired to process faces even when we do not see them clearly or even consciously (for review, see Johnson 2005). In sum, the visual system *wants* to see faces and animals.

The influential art historian Ernst Gombrich suggested that the visual system is attracted by certain patterns, since 'the greater the biological relevance an object has for us the more will we be attuned to its recognition – and the more tolerant therefore will be our standards of formal correspondence' (1963, pp. 6–7). The scientific evidence for rapid visual categorization, as well as the widespread phenomenon of pareidolia, support Gombrich's claim of perceptual tuning and our ability to recognize objects that appear deformed from the real thing. As Gombrich notes, there are obvious evolutionary advantages to a finely tuned sensitivity to face-like patterns. Infants, despite their initially poor visual acuity, are primed to recognize face-like patterns and this aids their social interaction with caregivers (Johnson 2005). Similarly, the survival of our ancestors depended on their ability to quickly recognize the presence of an animal in the environment. Poor 'recognizers', who failed to react to faces or predators, would not have been likely to pass along their genes. There is a fine line, of course, between recognizing subtle patterns and seeing objects that are not there. Interestingly, the subject matter of hallucinations tends to follow the same pattern as pareidolia. A recent survey of the phenomenological experience of Parkinson's disease sufferers found that a majority of hallucinations (over 80%) involved people, disembodied faces, or animals (Barnes and David 2001).

Artists may have taken advantage of this quick and coarse processing system in several ways. First, artists can provide only the 'sketch' and expect the brain to fill in the details. Cubism and Impressionism, for example, rely on the brain to reconstruct scenes suggested by a pattern, by exploiting perceptual memory (Cavanagh 2005). The ability of modern artists such as Picasso, Severini, or Miró to distort images while still evoking perception of faces demonstrates the brain's 'holistic' processing of faces based on the gestalt-like pattern, rather than specific details (Figs. 19.3 and 19.4).

Fig. 19.3 Gino Severini, *Ritratto di Madame M.S.*, 1913–15.

(Mart Museum, Rovereto)

Understanding this work by Severini requires a series of complex perceptual processes in which elements are grouped together in order to allow the recognition that this is a portrait of Madame M.S.

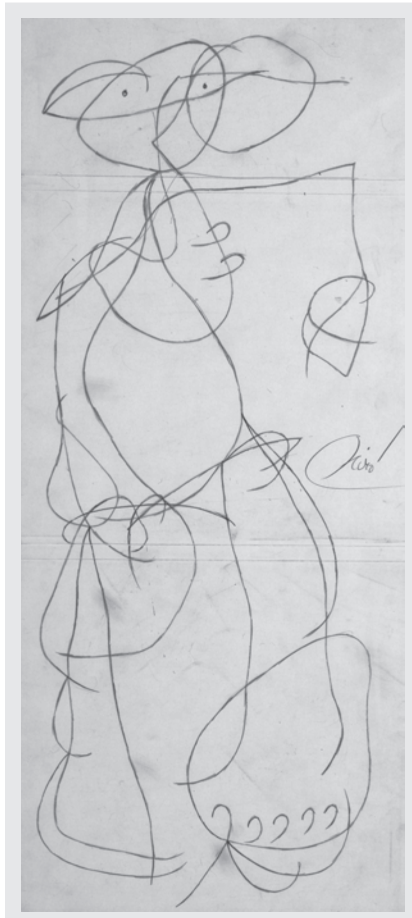

Fig. 19.4 Joan Mirò, *Homme et femme*, 1979.

(Mart Museum, Rovereto)

The tendency to see the human figure in patterns affords artists the freedom to creatively explore the male and female form in an infinite number of stylistic variations, as shown in this drawing by Miró.

Recognizing the identity of patterns is, after all, one of the basic functions of our perceptual system, so it makes sense that many people would enjoy pushing the system to its limits as a form of perceptual problem solving.

Second, it has been hypothesized that artists have used coarse information to specifically target emotional processing (Cavanagh 2005). Coarse information, such as Mooney patches of colour, is sufficient to trigger emotional responses in the brain even without awareness, while more detailed information is needed for recognition of the specific face (Vuilleumier et al. 2003). A painting with numerous distracting or, worse, inaccurate local details might hinder the rapid understanding of the subject matter by the slow pathway. The coarse information present in the work, on the contrary, finds rapid access to the emotions and areas of the brain involved in understanding the context and overall meaning of a scene. What happens, for example, with paintings using divisionist techniques (such as in many Impressionist works)? The fragmented and crowded texture and mottled brushwork in Impressionist painting do not hinder direct access to emotions, while such information would be distracting for the slow object-recognition pathway. This may help to explain the massive popularity of this artistic movement (and, in particular, artists such as Monet, Degas, and Renoir) with the untrained public. Does the experience of such works tap into the coarse (context/emotion) system instead than into the slow, conscious object-recognition system?

A third implication of the importance of coarse information in visual perception is that it leads to overly generous recognition of random patterns that happen to vaguely resemble a particular object. It is likely that people have always experienced pareidolia. So a rock formation in a cave or a chip of an antler bone might have reminded early humans of an animal such as a deer or bull, just as it does to us today. The oldest artefacts that are representational (that is, they appear now to us as looking like an animal or other object) are stones and bones that have, at least in some cases, been intentionally modified to better fit an interpretation. In the caves in Altamira, Spain, for example, there is an instance in which eyes were painted onto a protrusion in the wall that resembled an animal head (Nougier 1969; Cutting and Massironi 1998). One interesting hypothesis is that the first sculptures or paintings by humans were modifications of natural patterns—such as Alberti's marble faces—rather than a sudden inspiration to create representational art on a blank canvas (for discussion, see Melcher and Bacci 2008).

Cues for depth perception

Even with a flat image, people are able to understand the depth relations between separate objects when pictorial cues to depth are present. The principles of portraying depth in pictures have been addressed at length elsewhere (Kubovy 1986; Maffei and Fiorentini 1995; Livingstone 2002). Not surprisingly, many of the techniques that have been developed to portray depth take advantage of optics and the physics of how images are projected into our eyes. As such, they are more 'discoveries of physics' than principles of visual neuroscience. There are, however, a number of phenomena related to depth cues in pictures that may tell us something about how the brain processes the input from the eye.

First, in the majority of figurative artworks making use of perspective there are local depth cues that do not conform with the system used in other areas of the picture (Figs. 19.5 and 19.6). These local inconsistencies go largely unnoticed. Even in Renaissance painting, perspective was usually locally linear for particular regions of the painting, not consistent globally. For most artists, linear perspective was simply a tool for telling the story, or a device to show their cultural refinement, rather than a rule to

Fig. 19.5 Fortunato Depero, *Casolari diroccati*, 1943.

(Mart Museum, Rovereto)

Local perspective cues are sufficient to give the perception of depth, even when the overall construction of the scene contains multiple, incompatible vanishing points.

slavishly obey (see Panofsky 1927/1991). Our inability to notice this inconsistency without drawing lines on a reproduction of the picture provides further evidence that the brain does not calculate full three-dimensional representations of the world to view with our mind's eye where the errors would be obvious (Cavanagh 2005).

Second, even the most carefully crafted perspective scheme failed to capture normal visual perception. Leonardo da Vinci, for example, distinguished between mathematical perspective and true psychological perspective. One problem noticed by Leonardo was that a picture of a building with frontal columns that was made using linear perspective would result in columns of unequal width. Paintings and photographs, unless done in stereo, also fail to take account of the fact that we typically view the world with two eyes. Photography in particular has been described as the culmination of centuries of investigations on how to use optics to create a permanent, imitative depiction of a visual scene. However, one can argue that the influence of photography is not due simply to its potential to 'substitute' for painting: instead, photography also revealed the *limitations* of imitative optical depictions. Photographs could show that a painted image almost invariably contrasted with psychological perception of the same scene as captured by the camera. The public could evaluate for the first time how heavily artists edited reality, when painting, to fit the expectations of the

Fig. 19.6 Giorgio De Chirico, *Piazza d'Italia (Souvenir d'Italie)*, 1924–25.
(Mart Museum, Rovereto)

The shadows in this work are oriented in varying directions, consistent with the presence of more than one lighting source, yet this confusing feature is not typically noted by observers.

observers' eyes. In addition, many photographs do not look 'real' either. For example, the strange and unnatural way in which movement is often depicted by photography contrasts sharply with our perception of movement. The photograph raises the question: which is the real image: the one created by a camera or the one perceived in the mind's eye?

Contemporaneous with the advent of photography, Wheatstone's invention of the stereoscope sounded the death knell for the assumption that linear perspective reflected perceptual reality (see Pierantoni, Chapter 20, this volume). The stereoscope demonstrated a subjective perception of depth that did not correspond to *either* of the images shown to the separate eyes, challenging the idea that Renaissance perspective is truly an imitation of natural perception. The failure of linear perspective to capture 'perceptual depth' was laid bare, opening up a new investigation by art and science into perception and depiction of space. The first depiction by humans created the 'problem of depth', with the figure automatically perceived in front of the background. In the nineteenth and twentieth centuries, artists have taken up this challenge by exploring space and time, such as in Cubism or Futurism, or by attempting to create flat, 'optical' images (as championed by theorists such as Greenberg and Fried) that do not segregate into figure and ground (such as in works by Mondrian and Pollock).

One can argue that 'the trouble with optics is the trouble with photography: it's not real enough, it's not true enough to lived experience' (Hockney 2005). While this statement is open to interpretation, it does point out the fact that pictorial representation, when based on an artist's sensorimotor interaction with the world, necessarily differs from a single snapshot. Of course, photographers know that there is no such thing as 'the photograph' of a scene: even when a print comes from an unretouched single negative, it still reflects a series of decisions about focus, focal length, aperture, lighting, and composition. In a painting, artists have even greater licence to manipulate the observer's neural response by, for example, changing the surface properties, adding new colours, or enhancing the cues to movement.

Moving pictures and the portrayal of depth in cinema

Unlike a painting, in cinema the picture changes rapidly. Why are we not bothered by the many 'cuts' that suddenly change the picture shown during the movie? The director John Huston claimed that:

> all the things we have laboriously learned to do with film, were already part of the physiological and psychological experience of man before film was invented . . . Move your eyes, quickly, from an object on one side of the room to an object on the other side. In a film you would use a cut. . . . in moving your head from one side [to the other].
>
> (Quote from Messaris 1994, p. 82)

It is interesting to consider in what ways 'cuts' in movies have turned out to be similar and dissimilar to our use of saccadic eye movements and fixations in everyday life. First of all, cuts are typically shorter than saccadic eye movements (which are so long that we should, in theory, see an image smeared across the retina). The two dominant explanations for why we do not perceive smeared images are saccadic suppression (the brain 'turns off' input from the eye before the saccade begins) and a type of backward masking in which the new image over-writes the old (Matin and Pearce 1965). For both cuts and saccades, we know that the visual system is essentially blind during the first 100ms or so after the new scene arrives because conscious visual perception is slow.

There is some concern that MTV-style cuts may be changing the way that we perceive film, but even music videos tend to show relatively long shots between cuts, compared to the average length of stable eye fixation in everyday life. Film cuts that are too fast, not allowing the observer to update their perception before a new cut begins, are disorienting. The film *Easy Rider* (1969) includes single-frame cuts mixed in with longer cuts and such a technique breaks the illusion of the movies by drawing attention to the cuts themselves (Cutting 2005). The single frame, much shorter than a fixation, did not give the brain enough time to process the new image before a new one replaced it.

In addition to limits on minimum duration, cuts must also fulfil other requirements to avoid calling attention to their existence (Hochberg and Brooks 1996). One necessity is that the scenes are very different, from different angles of different objects and, when possible, with a variation in the lighting. These conditions, of course, mimic the differences in fixations that tend to occur after saccadic eye movements. Thus, one can conclude that a major factor in whether or not we notice cuts in films is the degree to which those changes in image match what happens when we move our eyes in natural scenes (Hochberg and Brooks 1996; Cutting 2005).

A third issue is viewpoint. This issue is most clear in photography and cinema, where an explicit choice is made about the location of the camera, but drawings and paintings may take advantage of the same techniques. A simple example is whether to film a mixed group of adults and children from the eye height of the child or the adult. Looking down is equated with dominance, while looking up with a more submissive role (Messaris 1994). Sidney Lumet's 1957 film *Twelve Angry Men* provides a useful example of how viewpoint can be manipulated for narrative effect without the audience noticing (Cutting 2005). The first third is filmed from eye height (for a standing person), enabling a wider view of who is sitting at the table. Then in the second third, the camera is placed at sitting eye height, where the discussion between the jurors is taking place. Memory allows us to remember who is where in the room. In the final third, the camera was lower slightly, eliminating from view the table top and, presumably, making each actor into more of an individual rather than part of a group sharing a table together (Cutting 2005).

The perception of depth can be strongly manipulated by the way in which an artist (or photographer) chooses to portray the texture gradient (Gibson 1950). In general, the texture of an object is most easily seen when it is nearby and when it is viewed at the centre of gaze. This particular depth cue has not been used widely in art history (it was often used, at least in some form, in Renaissance painting), becoming much more important with the advent of photography and, subsequently, cinema. The lens of the camera can be used to exaggerate or minimize texture in a photograph, because the image that it transmits presents, much like eyesight, an area of sharp focus at the very centre and a progressive loss of acuity in the periphery.

Cinema has even attempted to mimic the physiological accommodation of the eye. One exaggerated example is provided by *Vertigo*, where the zoom lens intends to simulate the visual component in the sensation of vertigo. As mentioned earlier, painters also use various tricks of perspective to focus the attention of the observer. A case in point is Mantegna's *Dead Christ* which seems to suggest that Jesus had very small feet compared to the size of his head. That Mantegna was simply mistaken in his use of perspective is one very unlikely possibility. Perhaps instead he chose to 'zoom' into the area of the scene that was most important for the narrative and emotional power of the work—the face of the dead Christ—by reducing the feet that were in the way. Modern filmmakers have the possibility, not available to Mantegna, to shift focal length over time and thus direct attention using these dynamic cues.

Illumination

What our eyes detect is the reflection of light off of surfaces. To our brains, this pattern of light is important mainly for allowing us to recognize and act upon objects. Thus, there is a basic distinction between the interpretation of visual perception as concerned with *light* or with *objects*. Artists may choose which of these aspects of perception are most important. The differences in style between Venetian and Central Italian schools (during the Renaissance) reflect these two sides of this argument. Venetian painting, influenced by the mercurial and atmospheric nature of illumination in that region of the world, often emphasized the play of light upon surfaces by privileging the use of colours over the linear construction of the image. It is an introspective approach that attempted to portray the phenomenological experience of the fleeting perception of colour and light as it happened with the flow of time. In contrast, the art of central Italy (such as Florence and Rome) was typically more concerned with portraying the solidity and depth of objects through the use of the line. Lighting, and thus colour, was a secondary factor and served to emphasize the three dimensionality of objects. In other words, these artists were mainly interested in those aspects of objects that do not change with the variations of light – in object permanence, one could say, rather than subjective transience. This impressive ability of the visual system to perceive objects as similar across different viewpoints and lighting situations is known as 'perceptual constancy'.

Artistic conventions to manipulate light and shade have served a number of purposes. The most basic manipulation, used at least since antiquity, is to lighten nearby surfaces and darken further away surfaces. One widespread device, described by Pliny the Elder, was to modulate the lightness of a folded garment so that the near fold was a lighter shade of the colour (see Gombrich 1960). One important caveat to note about this, however, was that the manipulations were entirely local. There was no attempt to make the source of the lighting consistent across the various objects portrayed in the scene. Now, computer generated graphics will perform these sorts of calculations as part of the rendering process. However, such technology may not be necessary since many inconsistencies in lighting are typically not noticed by the viewer. Thus there is no reason for artists to worry about overall consistent lighting and, in fact, there are several reasons to avoid consistent lighting, since often the 'impossible lighting' looks better. Photographers, for example, use a variety of techniques during shooting, development, and printing to manipulate the local lighting of scenes. Many of Steichen's most powerful prints (shot before the Photo Secession Movement) used burning and masking techniques that appear to represent, if one analyses closely, multiple lighting sources in the natural world which would only be possible by adding a few extra suns or moons in the sky (or manipulating the negatives in the darkroom). During his young years the trick of printing from a few different negatives, a process called 'combination print', was largely popular.

A similar situation is found with cast shadows. The use of shadows to portray three-dimensional form and depth has been intermittent in Western art (Casati 2004; Gombrich 1995). One finds examples in classical Greek and Roman works (paintings and mosaics), but it was not widespread until the Renaissance. Initially, investigations into painting shadows in the Early Renaissance can be described as an experiment in trial and error (Casati 2004). Eventually, knowledge about shadows was included in treatises of painting and canonized as part of European painting techniques (Casati 2004) In contrast, there are few examples of shadows in non-Western art before the reciprocal influence between East and West occurred in modern times (Gombrich 1995). Some artists used shadows for practical reasons while others did so to show off their bravura or even play visual jokes (Casati 2004).

Shadows are tricky objects for the scientific study of perception, since in many cases they are not necessary while in others shadows are a vital cue to interpreting ambiguous situations (Cavanagh and Leclerc 1989; Kersten et al. 1997). The brain appears to have a very limited understanding of physics when it comes to shadows—as shown in Fig. 19.6, we fail to notice when shadows are inconsistent with the lighting source or are even the wrong shape or colour (Casati 2004; Cavanagh 2005). One rule is that the shadow must be darker than the background. This rule is demonstrated by scientific experiments, but also apparent from observing the way that artists have represented shadows. In addition, shadows cannot look opaque (as if they are solid). This can be demonstrated experimentally by tracing a line with a thick pen around the edges of a cast shadow, which transforms our perception so that the shadow then looks like paint. Paradoxically, in order for a shadow to contribute to our understanding of shape in a picture, the shadow must first be recognized as such (Casati 2004).

In sum, the brain computes lighting locally, not across an entire scene. Before the advent of artificial lighting, the source of lighting in real life was fairly obvious (sunlight during the day, moonlight at night, and the occasional fire or candle). There is no 'lighting inconsistency detector' in the brain. On the other hand, the large changes in the brightness coloration of light during the day, as well as the reflectance properties of objects, have led to a sophisticated—but local—set of tricks to understand the true shape, lightness, and colour of objects in the world. Impossible lighting situations have now become commonplace in photography, film, cinema, and theatre. In a case of life imitating art, real-life performances with live actors can now include the use of differential local lighting strength and directionality and other features that have been used by pictorial artists throughout history.

Transparency and reflection

Our earliest experience in colouring surfaces in pictures is to fill in the space within the boundaries with a solid colour (colouring between the lines) to capture the actual or pure colour of the surface and ignore its variations (impurities) due to lighting or angle. Many objects, however, are shiny rather than matt. Moreover, many objects that one might want to portray in a picture are partially transparent rather than opaque. The importance of gold and jewellery in various cultures has led, naturally, to the desire to paint images that look like gold and jewellery. Likewise, transparent fabrics, glass, and water all might want to be included in a painting, as a testament to the artist's ability in imitating textures. Throughout history, artists have devised ways of making paint look like a different type of surface. The most obvious, but not necessarily most successful, strategy is to attempt to recreate the visual experience of a given material as closely as possible by using that same material as medium. Giotto used marble dust when depicting marble surfaces in the Cappella degli Scrovegni, presumably to try to convey qualities of the surface material that were difficult to replicate only with paint. Another example is the use of glass particles and gold highlights by Venetian artists. These artists were responding to limitations of the medium (al fresco or tempera) that made painting highlights impossible without adding white paint, which washed out the bright colours and weakened their intensity. For these artists, adding glass dust could give sparkle to patches of clothing, light, or water without compromising the saturation and hue of the colour. They were tackling the basic problem in painting of representing light without using a specific colour to indicate light.

One technical challenge for painters has been the depiction of diaphanous or semi-transparent surfaces such as lace or see-through materials. The simplest technique that artists can use is to 'overlay' the transparent material so that it crosses the contours of the background material. These crossings, known as 'X-junctions', appear to be critical for depicting transparency in a convincing way (Metelli 1974). Even a small misalignment of the X-junctions destroys the perception of transparency. Many other deviations from physics, however, are simply not noticed. One example is the depiction of refraction through a medium such as glass or water. The principles of refraction had to be discovered, but this discovery was not at all necessary for artists to convincingly depict objects such as a flower vase. Indeed, correct refraction is not necessary nor, surprisingly, does any refraction need to be depicted at all. People are typically perfectly happy with depictions of vases containing a mysterious liquid in which light moves exactly in the same way as it does in the air. If one believes the paintings, people have been drinking, swimming, and being baptized in this liquid air-like substance, throughout history. This 'found science' demonstrates that the visual brain takes into account only a subset of the information available in an image when determining the transparency of a particular surface (Cavanagh 2005).

Mirrors are another area in which perception and physics appear to part ways. Reflection on a mirrored surface has often been interesting to pictorial artists, allowing them to introduce another viewpoint in the painting without compromising the narrative continuity (Fig. 19.7). Examples include the classical story of Narcissus looking at his reflection in the water which has been found in mosaic form in Pompeii. Indeed, the two periods during which there was the greatest interest in optical images and reflections are late Roman and Renaissance art, when mirrors, glass, and lenses are most often included in painting. One fascinating question is whether this interest in

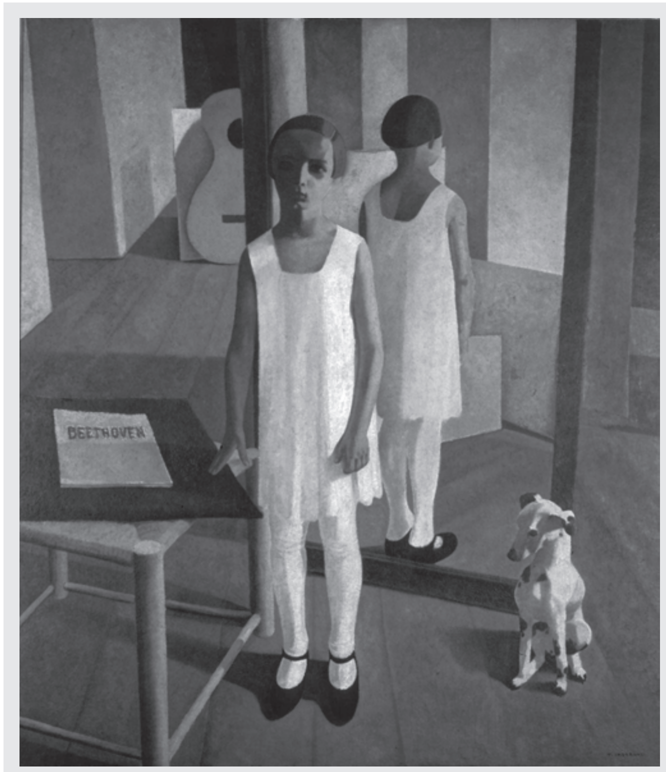

Fig. 19.7 Felice Casorati, *BEETHOVEN*, 1928.

(Mart Museum, Rovereto)

It is relatively unimportant to the viewer whether or not the artist has correctly calculated the exact position of the reflected image of the girl in the mirror. The visual system construes this image in terms of a mirror even though that is not the only, or perhaps even the most physically accurate, interpretation.

reflection coincides with interests in realism and in the use of reflected images as a tool for studying projections. In any case, one finds mirrors depicted since antiquity which, almost without fail, disobey the laws of optics.

What do paintings of mirror reflections tell us about our naïve physics? The answer appears to be that the history of painting shows that our brain has no understanding of mirrors. It really does not matter what angle of reflection is portrayed. One typical use of mirrors is to portray a person looking at his or her reflection in such a way that both the person and their reflection are shown—a physical impossibility. This basic ignorance of the physics of reflection is confirmed in experiments, which show that people are clueless about the size and angle of mirror reflections, even for the most basic type of mirrors used in bathrooms and changing rooms around the world (Croucher et al. 2002; Fleming et al. 2003). The reader can test her/his understanding of mirrors by answering the following question: how big is the reflection of your head in a typical wall-mounted mirror such as those found in a bathroom?[2] Ironically, physics students do not appear to understand mirror reflections either. Artists, while often not getting the physics right, showed a deep understanding of human perceptual psychology, and thus typically avoided making the few mistakes that would actually be noticed. Overall, reflections merely need to curve according to the curvature of the surface (if the mirror is not flat) and generally match the visual properties of an average scene (not necessarily the scene around the mirro (Fleming et al. 2003; Savarese et al. 2004). The brain cannot tell whether the mirror image is accurate or merely good guesswork: we do not notice any inconsistencies in famous works such as Van Eyck's *The Arnolfini Portrait* (1434), Caravaggio's *Narcissus* (c.1597–9) or Manet's *Bar at the Folie Berger* (1881–2).

Moving pictures

The brain is highly sensitive to motion cues, with specialized brain regions involved in detecting different patterns of motion. For the artist, there are two ways to portray motion: imply it with a static image or create a moving image. The advent of 'moving pictures' as a form of art and entertainment is a relatively recent development in art history. Of course the images do not actually move: the perception of motion is all in our head. There are psychological laws of motion perception that describe the spatiotemporal patterns that do or do not lead to motion perception. Film (and, later, television and digital computer files) involves an economic compromise that allows us to perceive smooth motion without wasting extra frames. This compromise works well for us because of the human brain's visual 'refresh rate', but probably looks like a flickering mess to a fly that wanders into the cinema.

With static pictures and sculptures, the problem of depicting motion, and more general change over time, remains a fundamental challenge. One can see even in the earliest cave paintings the way in which space and time dominate artistic choices. Portraying an animal will always give a sense of relative depth (the figure is seen against a background), while the pose of the animal will make it appear either lifelike or dead. Some cave paintings, even those 30 000 years old, appear to us today to show animals in motion (Cutting and Massironi 1998). Given the importance of motion in art, it is intriguing that the question of movement (time) seems to have received less attention than issues of depth (space) in art history (Gombrich 1982). How, then, is it possible to depict motion in static media such as sculpture or drawing?

The list of artistic techniques that can lead to an understanding of implied motion has been explored in more detail elsewhere (Cutting 2002). Here we will consider instead a basic question about art and brain: do we truly 'perceive' motion in a static

[2] The reflection of one's head is incorrectly perceived as life-sized by most people.

picture or is it a purely 'cognitive', abstract understanding? The first set of evidence for the former hypothesis comes from studies of 'speed lines' in pictures. These lines are used most blatantly and economically in cartoons and comics to indicate motion, but can be used subtly in paintings by making the object or background appear to blur, orient or stretch along the axis of motion. Recently, scientists have taken advantage of the body of knowledge about motion perception to investigate how viewing oriented lines affects it. A variety of experimental (Geisler 1999; Burr and Ross 2002) and neuroimaging studies using functional magnetic resonance imaging (fMRI) (Krekelberg et al. 2005) confirm that motion mechanisms in the brain take these lines into account in computing motion speed and trajectories. So it appears that speed lines are part of the knowledge base of artists about the neuroscience of the brain. As Kennedy has noted, even blind artists use such visual cues in depicting a moving wheel (1993).

Recent research suggests that the perception of motion in a static image is not strictly metaphorical: on the contrary, many of these stimuli activate motion-processing areas of the brain (Kourtzi and Kanwisher 2000; Senior et al. 2000). In these studies, observers were shown 'frozen-motion' stimuli (typically photographs) showing people in motion, pictures of people at rest, or dynamic motion stimuli. The question was how photographs depicting motion would be processed in the brain. Motion processing involves several stages, with 'low-level' brain areas that are sensitive to local motion signals feeding into 'higher' level areas that combine information over space and time. The common finding across these studies is that the earliest levels of visual stimulus processing, such as area V1 are only active for real motion (spatial-temporal change) and not for any of the photographs. Higher-level areas of the brain, which have been implicated in complex motion processing such as biological motion, become active for the frozen-motion stimuli but not the other photographs. Thus, it is now clear that static pictures portraying motion actually stimulate brain regions involved in perceiving real motion. It is not simply a cold, detached understanding of motion based on logical reasoning.

The results of these and related neuroimaging studies may provide a useful way of thinking, more generally, about pictorial depiction. One interesting finding in these studies is that 'secondary'—as opposed to primary—visual processing areas are most influenced by pictures portraying motion. Such processing areas in the brain are interesting for our purposes here, since these brain regions are multisensory and thus may *conflict* with information from unisensory processing areas. In other words, activation of intermediate areas such as V5/MT without motion signals from V1 may tell us 'this looks like it is moving, but at the same time there is no local motion'—thus we are not 'fooled' by an illusion, but we are aware of the perceptual (not merely abstract[3]) meaning of the depiction.

[3] It is possible to imagine an abstract, amodal idea of an object that is divorced from any particular sensory experience. For example, our mind has an abstract, symbolic representation of 'apple' that can be evoked by a word (spoken or heard), picture, or actual object (seen, touched, or tasted). Looking at a still life with fruit will, of course, call to mind this symbolic apple, but experience of the apple has a sensorial aspect that is specific to the way we perceive and recognize objects.

A second issue raised by these image studies is the influence of experience on picture perception. It is reasonable to hypothesize that the techniques used by artists to portray motion build upon other, earlier methods. Once the observer learns to 'see' motion in one type of painting, this increases sensitivity to those motion cues, which then influences how they see other artworks. This is a process known as 'perceptual learning' (Gibson 1963). One compelling example is provided by the pictorial experiments into the representation of motion that were central to the artistic practice of the 1910s. Artists as diverse as Picasso, Duchamp, and Italian Futurists such as Bragaglia, Balla, Boccioni, and Russolo were influenced the chronophotographic experiments of Marey and Muybridge. A recent experiment looking at how the brain reacts to such artworks may shed some light on how this developed. Two groups of students, one naïve to such depictions and the other well-versed in art history, were shown images of Duchamp's and Balla's paintings, 'static' abstract works (which do not give any impression of motion), and Marey's chronophotographs (Kim and Blake 2007). For both groups, motion-processing areas were active for the chronophotographs and inactive for the 'static' paintings. The main difference between the groups was that only the art students showed significant activation in motion-processing areas for the works by Balla and Duchamp. This experiment demonstrated, in agreement with other studies of perceptual learning, that experience can influence the way visual cues are used by the brain.

What is not clear from the imaging study is whether the change in the students' brains (which was also reflected in their perceptual judgements) was based on a direct influence of cognitive processes (explicit knowledge) on these motion processing regions, or whether the artistic training with 1910s artworks had influenced the way that the students paid attention to—and utilized—the motion cues that the artists had included in their works. Some evidence for the latter explanation comes from findings with another implied motion stimulus, the rotating rectangle. The rectangle stimulus, which gives an 'impression' of motion that continues into the future, does not seem to activate the same motion-processing areas found in the earlier study. Instead, the rotating rectangle appears to activate more 'cognitive' areas of frontal cortex implicated in expectations and prediction (Rao et al. 2004). Thus, it is reasonable to hypothesize that our experience of viewing art can influence both our expectations and—more interestingly—the way we actually see the world.

Biological motion

Our visual system is fine-tuned to detect 'biological' motion: the movement patterns of people and animals (Fig. 19.8). One of the seminal studies of biological motion is a study by Johansson and colleagues from 1973 in which actors were filmed under conditions in which only lights attached to parts of their bodies were visible. This extension of chronophotography (Fig. 19.9) separates motion and form information: it is impossible to identify the object based on form alone in any given frame. Only by combining

Fig. 19.8 Renato Guttuso, *BOOGIE WOOGIE*, 1953.

(Mart Museum, Rovereto)

The clever citation of the painting "Broadway Boogie Woogie" (Piet Mondrian, 1942-43) in the background allows this work to portray both biological and abstract motion in the same scene.

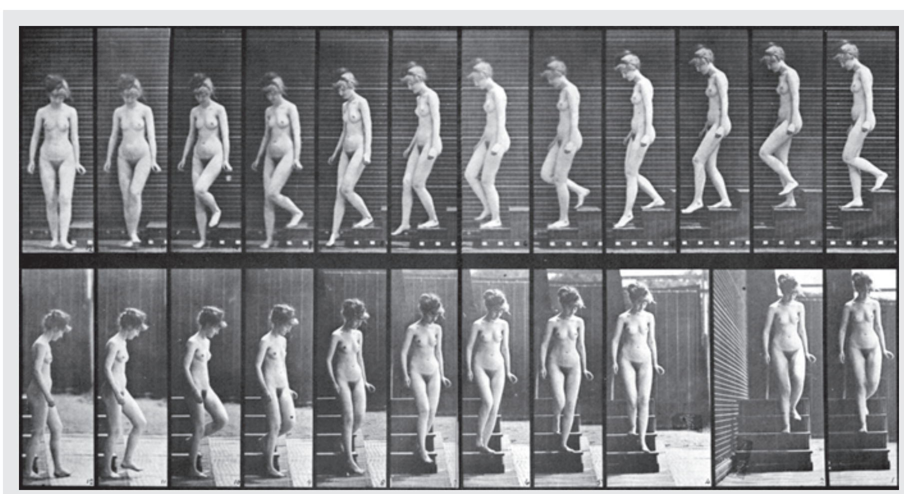

Fig. 19.9 Eadweard Muybridge, *Woman descending a staircase*, 1887.

(Mart Museum, Rovereto)

Human motion is constrained to follow certain paths, based on the structure and physiology of the body. This photograph by the pioneering photography Muybridge, from the book "Animal locomotion", captures brief instants within the complex action of walking down the stairs.

information across several different frames, over a period of up to 8 seconds (Neri et al. 1998), can the pattern of motion be understood.

A number of experiments have examined the nature of our perception of these ‘point light walker’ stimuli. The ability to understand these images does not require experience with movies: infants only 3 months of age (Fox and McDaniel 1982), as well as other animals such as cats (Blake 1993), perceive biological motion in these displays. Interestingly, the pattern of a few dots can yield quite detailed information, including the gender (Kozlowski and Cutting 1977), emotional state (Brownlow and Dixon 1997), and activity of the actor, such as running, leaning forward, or playing sports. Neuroimaging studies suggest that our brain has a specialized network for perceiving human and animal movements (Oram and Perrett 1994; Grossman et al. 2000).

Interestingly, we do not actually have to see *physical movement* (a change in spatial position over time) in order to perceive biological motion. As Socrates is reported to have noted in his discussion with the sculptor Cleiton, ‘by faithfully copying the various muscular contractions of the body in obedience to the play of gesture and poise . . . you succeed in making your statues like real beings’ (Xenophon, *Memorabilia* III X 7). The French sculptor Rodin brought this principle to its extreme consequences, inaugurating a way to portray motion in sculpture by representing the different limbs at different stages in the movement, so that the observer could ‘sense’ the motion unfolding in time—thus also proving how sophisticate our sensitivity to detect human motion really is. In other words, even static art forms such as sculpture, relief, drawing, or painting can create a ‘feeling’ of movement in the depicted agents (Freyd 1983). Studies of the ‘mirror neuron system’ (see essays by Gallese, Chapter 22, and by Calvo-Merino and Haggard, Chapter 27, this volume) suggest that some actions, particularly goal-directed actions, activate a ‘motor-like’ reaction in the brain which can even influence muscle tone. The eye is a channel by which images can influence the body and all the senses. The exquisite sensitivity to biological motion may be a precursor of the ability to understand, both through cognitive processes and the mirror neuron system, the meaning of a particular action.

Just as the interpretation of biological motion in a static picture can be influenced by previous experience, the mirror response to watching the action of another person also depends on our own experience with such actions. This idea has fundamental implications for our understanding of how people perceive pictures. Consider the example of dance. Art takes advantage of the human interest in dance and the inferred motion and pleasure in viewing it. The portrayal of dancers is a major theme in Asian and African artworks,[4] a fact which has greatly influenced twentieth-century Western art (Fig. 19.10). It is important to remember, however, that our ability to understand and interpret static dance positions depends on our personal experience with the real, dynamic dance movements. A recent neuroimaging study confirms the activity of

[4] Dance is a basic human activity found across many cultures. Many dances make use of visual props, such as masks constructed in ways that accentuate the impression of motion during the dance. Some African masks, for example, use reflective material for catching light, while Japanese ‘no’ masks change expression with change of head position.

Fig. 19.10 Robert Mapplethorpe, *Untitled*, 1981.

(Mart Museum, Rovereto)

This is a photograph of Grace Jones who had been painted by the artist Keith Haring. Andy Warhol introduced Haring to Jones and helped arrange for the photography session with Mapplethorpe. Jones is wearing a huge crown and rubber jewelry that were designed by David Spada. The influence of art-works from Africa on 20th century Western art is well known. At the same time, the interpretation of these artworks, in the West, has been influenced by generalization, ignorance and stereotypes, as cleverly exploited in this photograph by Robert Mapplethorpe. Here, the diverse elements of the decoration and pose of the model play into expectations and stereotypes, while the static (almost sculptural) pose and the medium of photography give the subject matter an "objective", Western view of the subject.

motor cortex while perceiving dance moves is influenced by personal experience with those dance movements (see Calvo-Merino and Haggard, Chapter 27, this volume). Thus, for example, the response of a typical Western museum-goer when looking at an African sculpture demonstrating the *dooplé* pose may differ fundamentally from that of member of the Quenon people (Ivory Coast) who would recognize the forward tilted torso, bent knees, open hands, and gaze fixed straight ahead as part of a dance pose (Tiérou, 1992).[5] Although the capacity to learn to discriminate biological motion from non-biological motion appears to be innate, the mechanism is flexible enough to be influenced by experience. This suggests that the influence of individual experience and culture is greater at the level of complex perceptions, such as the interpretations of particular movements, than for simpler features such as contour lines or depth.[6]

Our sensitivity to biological motion is a double-edged sword for artists. On the one hand, they can take advantage of the observer's sensitivity to body movement. However, this sensitivity to real bodily motion makes us particularly attuned to detect deviations from natural movement. The Renaissance art theorist Alberti, among others, argued that it was critical to understand the skeleton and the muscles in order to depict a realistic posture. The tricks required to create a natural pose become much more complex with dynamic stimuli. One telling example is computer graphics, which recently has been striving to move from 'cartoonish' depictions to hyper-realistic scenes in film and in video games. There are several interesting techniques that have been developed to incorporate knowledge about the structure and psychology of humans and animals into computer graphics. The 'skeleton system' approach, which started in the late 1980s in university laboratories, and then quickly moved to commercial and artistic applications, involves explicitly modelling the body's mechanical structure (skeleton, muscle, tendons, and so on) in the computer program used to create the image. The animation appears to move in a more natural way because its surfaces move in accordance with an underlying 'natural' structure.

A more advanced form of animation, 'artificial life', moves beyond body mechanics to also include a model of the basic 'psychology' (motivations and perceptions) of the organism. A computer model of fish, for example, can create a cartoon in which the fish move in a strikingly naturalistic way that makes them look like animals rather than drawings (Terzopoulos 1999). Their behaviour evolves over time, with the fish 'learning' how to swim based on the constraints of its body and influenced by its goals—such as seeking prey and avoiding predators.

[5] Artists have been great observers of anatomy and biological motion. Leonardo da Vinci, for example, studied the physiognomy and the physiology of emotional expression, and used this knowledge to detect which aspects of the face were critical in driving the facial expression. Many artists have attempted to draw 'the motion' rather than simply showing a static representation of a body in motion.

[6] The ability to perceive lines and depth disparities does depend on experience in early life. This flexibility is necessary because of the variability across persons in basic factors such as visual acuity and the distance between the eyes. Given normal visual input, most people naturally develop remarkably similar visual systems that have much in common.

Another interesting approach in computer graphics is 'motion capture', famously used in films such as *The Lord of the Rings* (2001) and *King Kong* (2005). The movement of a real actor's body and/or face are recorded as a set of discrete points that change position over time. These points are then 'grafted' onto a computer-graphic skeleton that changes in the same way. The results can be impressively realistic. The motion capture concept descends from ideas developed by the photographers Muybridge and Marey and later extended by Edgerton and by the psychologist Johansson (1973) in his point-light walker displays. In animation, the idea of motion capture was used by Disney studios in the 1937 film *Snow White*, in which animation stills were traced over film footage of real dancers (a technique known as rotoscoping, invented in 1915 by Max Fleischer). This fusion between art and science has been used extensively in dance, film, and also for popular entertainment.

Thus, the most straightforward way to depict human motion is to 'record' and copy the motion of real humans. For a painter, this is not an option. Alberti suggested that painters and sculptors began with an understanding of the skeleton and muscles, in order to understand motion and pose, through the dissection of cadavers, when possible, and anatomical studies on faithful wax models. Leonardo's intense study of anatomy, body postures and physiognomy is well known. What is fascinating about this combination of art and science is how it emphasizes the way in which our perception is based on an understanding of what is *beneath the surface*. Artists, as super-perceivers, have tried to understand the driving force behind the optical data. Scientific evidence, along with the more practical evidence of the usefulness of 'motion capture' techniques and 'artificial life' provide, instead, support for Alberti's idea that the artist must understand what is beneath the surface, beyond the optical projection, to capture the coming-to-life ingredient of biological motion.

The gaze and the moving eye

One great myth about visual perception is that the eye is like a photographic camera. The *camera obscura*, and later devices that fixed an image permanently, were designed based on the optic principles of a pinhole camera like the eye. While there is some similarity between the eye and the mechanical camera, it is clear that in terms of the medium for imprinting the image one would never want to imitate the human eye. In fact, it is difficult to overstate the extraordinary difference between the image at the back of the eye and what we perceive. A partial list of the terrible flaws in the retinal image that is passed to our brains includes: (1) the image is only registered at high resolution at the very small portion in the centre, with most of the peripheral vision mainly useful only for detecting movement and no details; (2) there is a complete lack of uniformity in the presence of each type of cone (colour receptor) across the retina, with very few cones outside the centre; (3) there is a big hole in the image at the 'blind spot' where the optic nerve leaves the eye.[7]

Since clear and colourful vision is only possible at the centre of gaze, we move our eyes an average of three to five times per second in jumping 'saccadic' eye movements. When it comes to vision, the eye is physically drawn towards what it perceives, in a perception-action cycle: 'The lover is drawn by the thing loved, as the sense is drawn by that which it perceives' (Leonardo da Vinci, Notebooks, Tr. Tav. 9a.). Each day, it is estimated that we make more saccadic eye movements than beats of the heart. Contrary to this jumpy visual input, our perception is smooth and continuous.[8] We are also capable of making smooth eye movements, but only when we are following with our gaze something that is moving within a certain range of speeds. Metaphorically, active vision works somewhat like sonar. We direct our gaze towards a region of space and then wait for the results to hit the retina. Then we move our eyes again and this decision of where to look determines what we see. There is a perception–action cycle of eye and head movements which bookmark brief periods of relatively stable fixation. Eye movements are typically accompanied by a shift in our attentional focus. While it is possible to covertly shift our attention elsewhere from our gaze (perhaps to allow us to scrutinize someone without being caught), shifts in gaze and attention tend to go together.

The consequence of vision with a roving eye is that we never see a scene in uniform detail and colour. This has numerous implications for understanding how people make and perceive artworks. As the art historian James Elkins notes, 'each act of vision mingles seeing with not seeing' (1996, p. 201).[9] Looking at details of specific objects requires us to move our eyes and head and, thus, even stationary objects move across our retina as we look around. The way that our visual system interacts with our eye movements leads to different time scales of perception. When viewing a painting, for

[7] It is extraordinary that there are no known records indicating knowledge of the blind spot previous to 1668. Leonardo had claimed that perception was actually best at the point where the optic nerve enters the eye (mistakenly equating it with the retinal *fovea*, where acuity is highest). The physicist and priest Edme Mariotte published a small book in 1668 (*Nouvelle Découvverte touchant la veüe*) based on a simple perceptual experiment that is now replicated in perception classes around the world. Mariotte's demonstration was popularized at the Academie des Sciences (Mariotte was a founding member) and taken 'on tour' for various audiences.

[8] One of the first to notice the fact that saccadic eye movements must pose a 'problem' that our brain must solve was the Persian scholar Alhazen (Ibn al-Haytham, 965-1040). He proposed that the mind must have developed a 'habit' that would take into account the differences between the retinal motion caused by eye movements and by motion in the world.

[9] The important distinction between the vast visual field and the small subset of the world that is actually perceived by the mind has a long history. Examples include Aristotle's theory that it is impossible to perceive two objects simultaneously (*On Sense and the Sensible*, 350 BC), the Stoic concept of the 'phantasia *kataleptikê*' that compares looking to grasping sensations by the mind, Lucretius' idea of vividness in perception (*De rerum natura*, *50 BC*), Alhazen's *vis distinctiva* (1040), Leibniz's 'perceptions petit' (*La Monadologie*, 1714), and, more recently, in Wundt's introspectionism and the beginnings of psychology. Freud's ideas of the unconscious have had a great impact on artistic production and an unrelenting influence on art criticism.

example, some visual information is specific to that moment and vanishes from our mind after eyes move on to a new position. Other visual attributes are combined across separate fixations over periods of time measured in fractions of a second (Melcher and Morrone 2003). Details about the visual properties of objects and their locations can accumulate over a period of tens of seconds and persist in mind (Melcher 2001; Tatler et al. 2005), allowing us to keep track of objects in common tasks such as making a sandwich or cup of tea (Land and Hayhoe 2001). Most of these visual details will be forgotten days or weeks later (Melcher 2001). Critically, none of these different visual representations over different time periods is like an image in your head that matches exactly the painting on the wall.

Separate aspects of the painting inhabit different mental places in space and time. One can heuristically examine this problem by observing Cubist paintings or, more recently, the photocollages by David Hockney and Polaroid collages by Joyce Neimanas. These images, like cubist artworks, draw our attention to several fundamental differences between paintings and perception.

First, as described earlier when discussing depth, there is a basic discrepancy between the perception of depth by humans (Leonardo da Vinci's *natural perspective*) and the transformations required to create pictorial representations of depth (*artificial perspective*). This problem becomes infinitely more complex when head and body movements are allowed. There are a number of view-point dependent effects when looking at perspective paintings that we tend to ignore. For example, Deregowski and colleagues have argued that the phenomenon of viewing converging lines as parallel—a foundation of linear perspective—does not hold for oblique views (Deregowski and Parker 1988; Deregowski et al. 1994). On the contrary, observers may judge *converging lines* as parallel under many conditions, in agreement with pre-Renaissance perspective. Another aspect of real-world viewing is that the position of the head and the focus of gaze tend to shift significantly when looking around a real scene. In other words, we often look at one side and then shift completely to look in the other direction. Thus, converging perspective may portray more accurately what it is really like to make these dramatic shifts in view, since it is impossible to have the same vanishing point for a glance 45 degrees to the left of centre and 45 degrees to the right.

Another interesting example is the fact that our eyes converge when viewing near objects and diverge when we stare off into the distance. Leonardo portrayed the struggle to focus the eyes (which he observed in the immature infant's visual system) beautifully in the *Benois Madonna* (c.1478). When our eyes diverge, they gaze into 'optical infinity': the parallel lines of gaze do not meet. Filmmakers, like painters, use depth planes (in particular, the furthermost depth plane in a shot) in order to manipulate the feeling of space and openness. At this point, there is no clear evidence about why it 'feels' different to see the horizon or to be walled in (although estate agents include such information in calculating property prices). Presumably, for our ancestors, a large vista would have been useful for safety and for finding important resources—even today people travel *en masse* to 'outlook points' where they can see far distances. Like in film, painters have exploited convergence and divergence as a cue to depth. A picture blocking the perception of the horizon can create the impression that the subject matter is closer or even closed in. One can compare David's *Death of Marat* (1793), where a wall behind the dead activist blocks our view, to Gerome's *Death of Ceasar* (1867) with the full perspective that continues into the distance. The former is more closed, claustrophobic and anxious, while in the second painting the vanishing point in the distance underplays the supposed tragedy and makes the cadaver go unnoticed even though it is in the foreground. A similar theme from the same period, which combines the two methods, can be found in Manet's *Execution of the Emperor Maximilian* (1867), where the wall blocks the horizon at eye level thus making the scene take place almost in our personal space, but an escape for the eye is allowed at the top of the painting above the wall.

Are there visual preferences?

Thus far, we have only considered the techniques which an artist could use to depict the existence of a certain object, scene, or event in a picture, without asking the question of why observers might actually like to see some of these features in an image. Inherent in this question is the intuition that our sensitivity to particular visual cues is somehow tied to our response to an artwork that uses those cues. Gombrich argued that artistic techniques were like 'the forging of master keys for opening the mysterious locks of our senses to which only nature herself originally held the key' (1993, p. 33). Thus, for example, our sensitivity to colour allows the artist to access the ability of those visual processing mechanisms that make the observer think and feel. At the same time, scientists face an enormous explanatory gap between showing that an aesthetic object activates a particular visual process in the brain and understanding *why* that visual object produces an aesthetic experience. The basic problem is that a great number of objects activate visual areas, and most of these objects are not considered artworks (see Hyman 2006).

Visual preferences can be studied at various levels of analysis. At the simplest level, certain techniques make images easier or more difficult to interpret. A blurry image will tend to cut out high spatial frequencies for example. There is some evidence that, in a world saturated with images, many people prefer stimuli that are slightly challenging (see Schifferstein and Hekkert, Chapter 28, this volume, for a discussion of the MAYA principle in design). Alternatively, certain techniques may focus our attention on one particular feature, such as colour, shape, or motion. Although some have suggested that it is this 'super-stimulus' itself, by effectively driving the neurons in the visual system, which leads to visual preferences (see Ramachandran and Hirstein 1999; Zeki 1999), this idea is controversial and seems to fall into the aforementioned explanatory gap (Hyman 2006).

If preference is not based on exaggeration of bright, colourful, moving stimuli, then how could a particular feature cause an aesthetic response? One limiting factor might be that certain features give access to the brain's reward system, based on experience and, to some extent, innate tendencies. The colour red, for example, has the potential to stimulate the limbic system—colour is tied to the motivation system because it is critical to survival: red is the colour of blood or raw meat, it is the colour of ripe fruit and dangerous animals. In other words, it makes sense to be aware of the colour red and to associate this colour with the reward system in order to survive. The exact nature of this association will depend on a lifetime of experience.

Another example of this complex mapping between visual features and the brain's reward system is shape. The visual system is highly sensitive to shape, a fundamental visual property. This allows artists to 'suggest' a particular visual interpretation (such as the three-dimensional shape of an object), but it is also an expressive tool to suggest a particular emotional state. In a series of recent studies, neuroscientist Moshe Bar and colleagues have shown that curved and pointed shapes influence people differently and that this difference is correlated with the way that sharp corners (potential dangers) activate the amygdala (Bar and Neta 2006, 2007). The work of Bar and Neta suggests that one of the 'master keys' used to artists might be explainable in terms of visual neuroscience: jagged lines and pointy corners, through their greater activation of the amygdala, offer expressive power to the artist. Given the importance of round versus sharp corners for most people, this artistic tool might tend to work across cultures. In contrast, many other of our shape associations are specific to our own experiences and culture. Laboratory studies have shown that simply associating a particular shape with an otherwise affective stimulus (such as a picture of a gun or a smiling baby) can lead to a change in preference for that shape—even when the participant does not consciously remember this association (for review, see Ghuman and Bar 2006).

Thus, there are at least three key elements to visual preferences. First, visual preferences depend fundamentally on what the visual system processes: no one can like or dislike ultraviolet light or pitches beyond our hearing range. Our sensitivity to features such as symmetry or colour is a precondition for preference for certain values of those features. Second, some preferences are likely based on deep rooted links between certain visual features and the brain's 'survival system' that manages our search for food, safety and reproduction. Third, these building blocks of pictorial (and non-pictorial) representation have flexibility and cultural specificity. Preferences, such as for particular faces, is directly influenced by our 'diet' of images of faces (for review, see Rhodes et al. 2003). Overall, the sensitivity to particular visual features, and their link to the brain's reward system, provides an expressive tool that artists can use not only to simply make a picture, but to imbue that picture with other suggested resonances.

It is interesting to note that the overlap, within the brain's reward system, between the neural activation to different stimuli that people prefer, including one's favourite music, food or touch sensations (Blood and Zatorre 2001; Kawabata and Zeki 2004; Di Dio et al. 2007; Stice et al. 2008; see Calvo-Merino and Haggard, Chapter 27, this volume). This suggests interesting commonalities between the various arts and also that certain multisensory artforms might be able to lead to an additive, simultaneous stimulation of the reward system. Interestingly, these brain areas also seem to be 'social'—they are also involved in our responses to appropriate or inappropriate behaviour within the set of rules (Tabibnia et al. 2008). This flexibility to social mores may be critical in shaping behaviour, but it also suggests that inappropriate behaviour can truly be 'ugly' and that the link between good and beautiful is not accidental.

At the same time, the distribution of features within a composition also seems to play a role in preference (Arnheim 1974). Great artists seem to manage a complex balancing act in which the elements fit together in some undefinable, yet satisfying way (Fig. 19.11). As Le Corbussier argued, in the context of architecture, 'the true and profound laws . . . are established on mass, rhythm and proportion' (p. 286). Every choice by the artist works within the context of the entire work: individual features do not exist in isolation. Much work in vision science has attempted to better understand the role of the centre, of symmetry, and of composition in artworks, investigating principles such as golden ratios that recur throughout art and architectural history, and indeed in nature (for example, Locher 1996). In addition, recent studies have also begun to elucidate mechanisms that may underlie balance in terms of visual features in a composition. For example, studies on 'feature-based attention' show that paying attention to a particular value of a feature (such as the colour red or rightward tilted lines) increases the response of neurons to other matching features (Maunsel and Treue 2006; Melcher et al. 2005). Thus, there are long-range interactions between

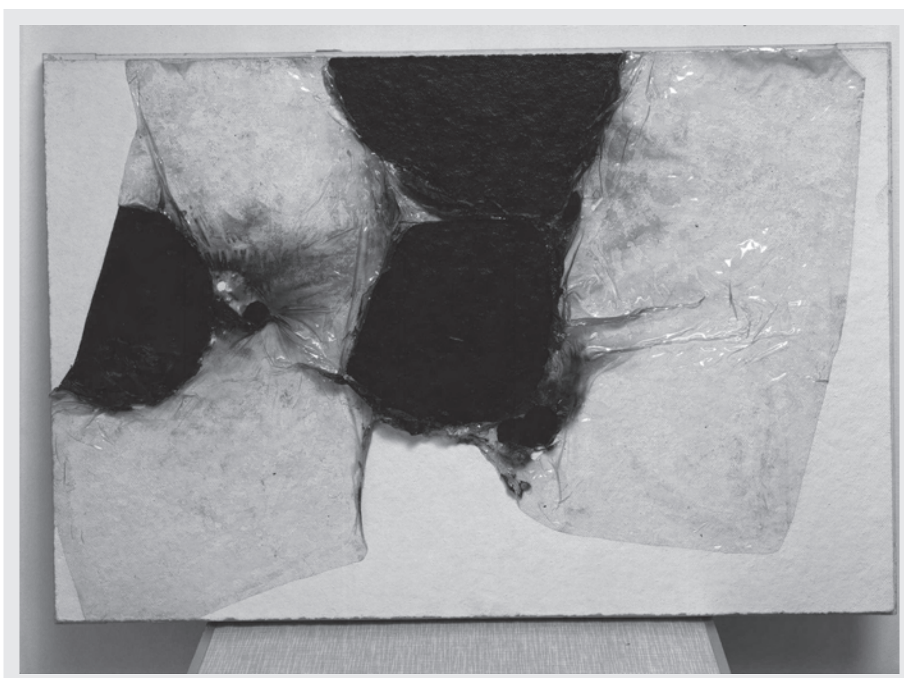

Fig. 19.11 Alberto Burri, *Bianca Plastica BL1*, 1964.

(Mart Museum, Rovereto)

Many artists balance the elements within a picture, using both relatively simple proportions and more complex balancing acts in which elements seem to fit together in intangible ways.

certain features, based on perceptual opposites (red/green, blue/yellow, up/down, left/right and so on). In a well-balanced composition, paying attention to the red square on the left does indeed 'call forth' the red shapes in the other side of the screen, so that the firing of neurons in the brain create an expectation that may be met when matching features are found in other areas of the visual field.

Conclusions

Our brains are extremely ready and able to interpret flat images in terms of the three-dimensional world. This fact, by itself, is an incredible scientific discovery. It is widely accepted, within the scientific community, that picture perception reflects properties of how the brain normally works, rather than simply a cultural convention. As described in this chapter, pictures embody hidden knowledge by artists about how the brain works and our willingness to interpret patterns of light and dark on a flat surface in terms of meaningful objects in spatial relationships to each other. One implication is that the brain does not necessarily represent the world, in terms of internal computations, as a full three-dimensional scene. In other words, there is no theatre in the head in which a recreation of the world takes place. We must continually, using our eyes, brains, and body, interrogate the world for more details. When it comes to cues from lighting, this information is strictly local. Otherwise, if the world in our head really was three-dimensional, then flat images should be distorted perceptually when we move. There could be only one seat in a movie theatre and each painting would need to be viewed through a pinhole. At the same time, people rarely confuse pictures with the scene represented in the picture. *Trompe l'oeil*, for example, works at its best with constricted observer motion and viewing from a relatively far distance so that small head and body movements do not break the illusion.

Certain techniques in pictorial representation enable artists to turn pigments into perceptions. Understanding these rules does not, by itself, lead to the creation of 'art', just pictures. It is critical not to confuse recognition with aesthetic experience. On the contrary, any painting can potentially provide a discovery in the alternative physics of pictures and, therefore, the psychophysics of the visual brain. Many of the rules of physics which constrain real scenes are optional in pictures. It is the choice of the artist, based on her or his goals, whether or not to obey the rules discovered by science. Such basic transgressions of standard physics, including contours, blurry images, impossible reflections, or shadows, tend not to concern the observer. For the neuroscientist, previously unnoticed differences between pictures and real physics can be viewed as data, as basic discoveries about the visual brain. For artists, on the contrary, these deviations may allow them to more effectively and economically achieve their aims. For the viewer, the picture can then be used as a stimulus that sets off a chain reaction of events in their body and brain. The outcome can influence the emotional and bodily state of the observer. Pictures, rather than mere copies of the world, can be a conversation between minds.

Interestingly, recent studies suggest that learning how to look at art can improve our ability to notice fine details. The *Journal of the American Medical Association* published a study showing that training in noticing the details of paintings lead to an improvement in detecting medically-relevant details in patients (Dolev et al. 2001). Training in art has become part of the core curriculum at Yale University medical school. Thus, the history of art and science, somewhat artificially segregated from each other in recent times, forms a circle, with art influenced by the study of anatomy while artistic depictions of anatomy have then been used to foster further scientific and medical research. The sculptor Henry Moore expressed a similar idea when he stated: 'All the arts are based on the senses. What they do for the person who practices them, and also the persons interested in them, is make that particular sense more active and more acute.' For the neuroscientist, looking at art can provide deep insights into the physics that matters to the visual brain.

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