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LEFT AND RIGHT IN SCIENCE AND ART

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Abstract—*An asymmetric object can exist in two left-right mirror-image forms,* enantiomorphs, *a phenomenon which has fascinated philosophers, cosmologists and artists. Psychologists and neurophysiologists have been particularly puzzled by the extreme difficulty children and other animals have in learning to distinguish left-right mirror images. The authors propose an explanation of why mirror images are so confusing. In the natural world almost all mirror images are actually two aspects of the same object, for example, the two sides of a face or a silhouette viewed from the front and back. Therefore a perceptual mechanism that treats mirror images as equivalent would be adaptive. The perceptual equivalence of mirror images only becomes maladaptive or confusing under very special conditions. One of these is learning an orthography containing mirror images such as* b *and* d. *Difficulty in learning to read, may, in part, be due to difficulty in overcoming the normal tendency to treat mirror images as the same stimulus.*

In the final portion of the paper the authors consider the effects of mirror-reversing a painting and, more generally, left and right in pictorial space. They suggest that some pictorial anisotropies, such as profile orientation, reflect the influence of lateralized brain functions, whereas others, such as the tendency to look at a picture from left to right, are cultural conventions.

How is the left hand different from the right hand? The paradox that an asymmetric object can exist in two mirror-image forms has fascinated philosophers, artists and scientists for a long time (Figs. 1 to 4) and still bewilders children trying to distinguish b from d and s from ƨ. This essay will consider two aspects of the perception of left and right. One is the difficulty of distinguishing enantiomorphs—of telling left from right mirror images. The second is the role of left and right in art. We will suggest that present-day ideas on brain function and its evolution may help elucidate both phenomena.

I. LEFT, RIGHT AND COSMOLOGY

Is there a 'left' and 'right' in the universe? Newton said yes, and Leibnitz said no. Newton thought that the coordinates of space were absolute and 'God-given'. Leibnitz attacked this view and argued that left and right were 'in no way different from each other' [1]. Kant was puzzled by enantiomorphs for decades and they led him to side with Newton [2]. For Kant the difference between left and right mirror images was literally 'inconceivable'. They could only be distinguished through intuition, through the *a priori* structure of the mind, and therefore for Kant, the *a priori* left-right structure of the universe [3]. Until very recently, however, cosmologists agreed with Leibnitz: the universe was symmetrical and right and left were arbitary human conventions.

The problem was of strictly theoretical interest until many astronomers came to believe that there must be millions of inhabitable planets and therefore probably other beings at least as intelligent as humans. Distinguishing between right from left then became of practical importance for developing a method of extraterrestrial communication. A digital code is clearly the best

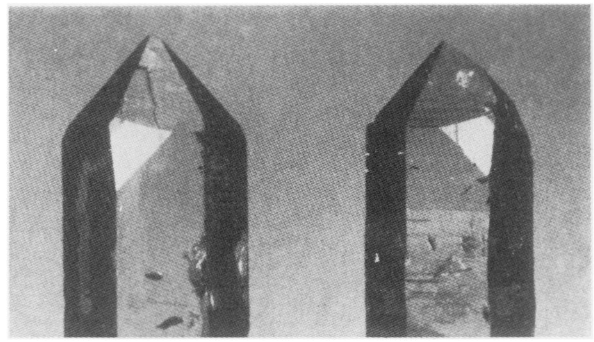

Fig. 1. *Quartz crystals* [from the Nobel prize address of V. Prelog, Chirality in Chemistry, *Science* 193, 17 (1976)].

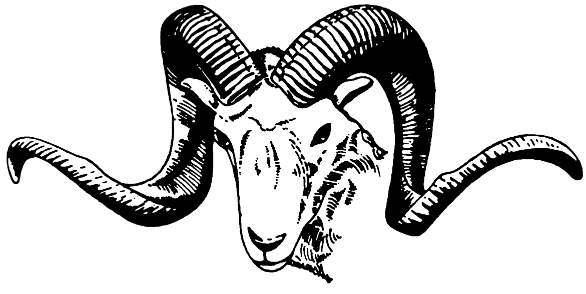

Fig. 2. *Horns of Marco Polo's sheep* [from D. W. Thompson, *On Growth and Form* (Cambridge: Cambridge Univ. Press, 1969)].

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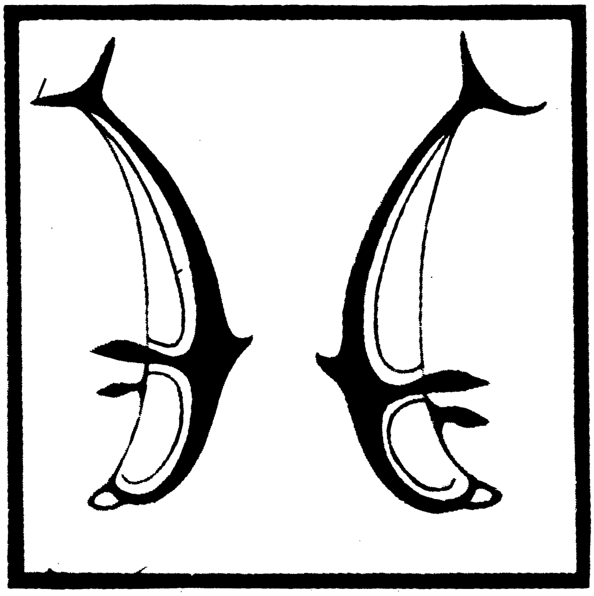

Fig. 3. *Floor pattern from the palace, Tiryns, Greece. Note that the two sides of a vertebrate are enantiomorphs* [from M. H. Swindler, *Ancient Painting* (New Haven: Yale Univ. Press, 1929)].

Fig. 4. *Stylized bear from the Tsimshian Indians of the north Pacific coast. Note that the right and left sides of this or any other pattern with a vertical axis of symmetry are enantiomorphs* [from F. Boas, *Primitive Art* (N.Y.: Dover, 1955)].

method, since it can be used to transmit pictures as well as messages. In order to decode pictures properly, it is necessary for the receiver to understand the instructions top and bottom, front and back, and left and right. Top and bottom can be described as 'away' and 'toward' the center of a planet. Front and back can be described as 'near' and 'far'. But how does one describe left and right to an extragalactic listener? Describing left and right requires the sender to point to and the receiver to look at one side of an object, but this is impossible intergalactically [4].

The solution to this problem came in 1957 from an experiment by Chien-shung Wu at Columbia. Her experiment shook the very foundations of modern physics: parity had fallen. Madame Wu studied the emission of electrons from cobalt-60, a radioactive isotope of cobalt. Normally, electrons are emitted in all directions from cobalt-60, but, when it is cooled down near absolute zero (−273°C) and placed in a strong magnetic field, the electrons would be expected to line up with the magnetic field and emerge equally from the two poles of the isotope nucleus. What Wu discovered was that more electrons came out from one side than the other of the otherwise uniform nucleus. Thus it was possible to label the poles of the magnetic field and therefore right and left in a consistent fashion. Right and left could now be given a meaning beyond human convention. Leibnitz was wrong: the universe is not symmetrical. Now, by describing Wu's experiment to our extra-galactic audience we could tell them about left and right, and about which hand most humans write with [5].

II. WHY ARE MIRROR IMAGES CONFUSING?

Like philosophers and physicists, children and psychologists have been confused about left and right (and cobalt-60 is unlikely to help them). The interest of experimental psychologists in left–right confusion began with the 19th-century physicist–philosopher Ernst Mach who noted that 'children constantly confound the letters *b* and *d* and also *p* and *q* . . . [and] . . . adults too do not readily notice a change from left to right' [6]. Since then there has been an enormous volume of literature on letter reversal and, more generally, on the confusion of mirror images. A practical spur to this research has been the problem of reading disability because of its frequent association with letter reversal. The theoretical interest in mirror-image confusion is that it occurs in a variety of species such as octopus, fish, rats and monkeys as well as human infants, children and adults. The ubiquity of mirror–image confusion must therefore reflect something fundamental about how the nervous system processes visual information [7].

Mach had suggested that the bilateral symmetry of the brain and body of the perceiver underlay mirror-image confusion and that to the extent that mirror images could be distinguished 'slight asymmetries. . .particularly in the brain' were responsible. In one version or another, essentially the same explanation of mirror-image confusion has been traditional in psychology ever since. The commonest version has been that of Samuel T. Orton [8], still the dominant name in the treatment of reading disorders. Orton thought that because the two cerebral hemispheres were mirror symmetric a visual stimulus on the retina would produce patterns of 'neural excitations' in each hemisphere that would be mirror images of each other. Therefore, in order for a stimulus to be distinguished from its mirror image, the hemisphere with the veridical excitations would have to 'suppress' or 'dominate' the hemisphere with the mirror-reversed excitations. Mirror-image confusion, according to Orton, was ascribable to 'incomplete dominance' of one hemisphere by the other.

Recently, Corballis and Beale [9] have produced a new version of the Mach–Orton idea that mirror-image confusion derives from the symmetry of the brain. Like Orton, they proposed that mirror-image confusion results from mirror-image representations of a stimulus in the two hemispheres. However, they realized that Orton's claim that an asymmetric stimulus would produce enantiomorphic patterns of stimulation in the visual areas of each hemisphere is false and that, in fact, the pattern in the two visual areas would be veridical and identical. Instead, they suggest that after the 'neural excitation' is stored as a topographic memory in each hemisphere, the 'memory representation' would mirror reverse when it transferred across the midline to the opposite hemisphere. (They assume that symmetrical points in each hemisphere are interconnected.) Thus each hemisphere would contain memories of the stimulus in both its veridical and its mirror form. According to their hypothesis, since every stimulus is stored in each hemisphere in its original and mirror-reversed forms, the organism would treat the two enantiomorphs as equivalent and therefore confuse them.

There are several serious difficulties with the various versions of the idea that mirror-image confusion derives from brain symmetry. One is presented by Gerstmann's disease. This disorder is characterized by extreme left-right confusion and follows damage to the left parietal lobe of the brain [10]. In this case an abnormally asymmetric brain increases left-right confusion rather than reducing it, as would follow from the Mach–Orton–Corballis hypothesis. Another argument against the role of brain symmetry comes from a comparison of children and animals. Both have severe difficulty in mirror-image discriminations, but the two hemispheres in children are functionally and anatomically asymmetrical, while in animals (at least below great apes) they appear to be completely symmetrical [11].

As mentioned above, Corballis and Beale realized that the initial representation of a stimulus in the two hemispheres would be veridical, not reversed as Orton has thought, and they suggested that the reversal would occur at a subsequent 'memory' stage. However, this idea is also unsupportable by modern visual anatomy and physiology. The left visual half-field is represented in the right hemisphere and the right visual half-field in the left hemisphere as shown in Fig. 5. Moreover, there are

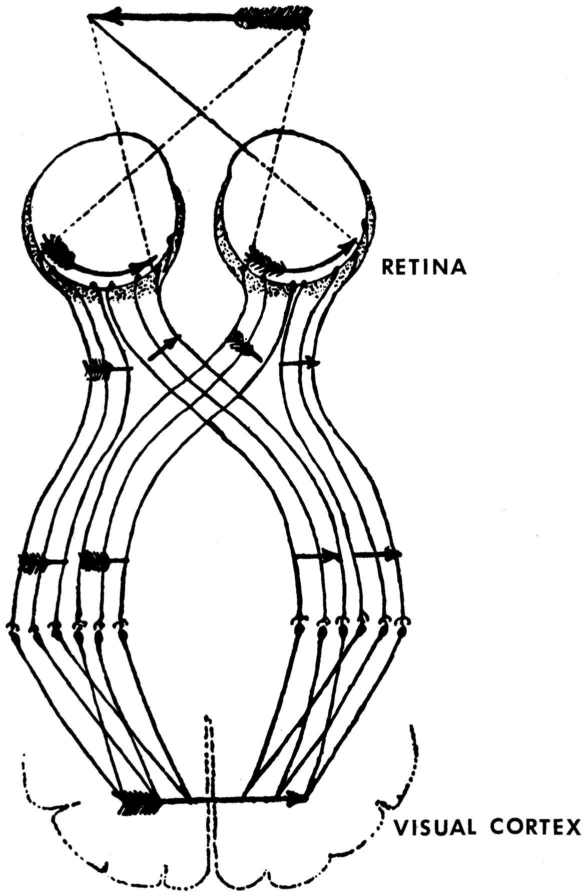

Fig. 5. Diagram of the visual pathways from Ramon y Cajal's classic Textura del sistema nevioso del hombre y de los vertebrados (Madrid: Moya, 1904). *The labels have been added. Note that the optics of the eye reverse the image of the arrow on the retinae. The nerve fibres from each retina separate so that messages from the left half of each retina travel to the visual cortex of the left hemisphere, and the messages from the right halves travel to the visual cortex of the right hemisphere. Thus when the center of the arrow is fixated (as shown) information in the left half of space (the arrow head) goes to the right cortex, and information in the right half of space (the feathers) goes to the left cortex. Note further that the two cortical representations are not mirror-reversed with respect to each other.*

multiple representations of the left half of space in the right hemisphere and of the right half of space in the left hemisphere [12]. However, the only anatomical connections between the representations of the left field in one hemisphere and the right in the other are between the representations of a narrow midline strip of the visual field [12, 13]. This interconnection does not carry information about integrated visual patterns [14]. At this stage there are no longer any maps of visual space to be reversed. (However, the absence of evidence for an anatomical mechanism for interhemispheric reversal of memory traces is not a conclusive argument against the possibility of such a mechanism. After all, we learn and remember, and the anatomical bases of these phenomena are still totally obscure.)

More damaging for the Corballis and Beale hypothesis is that attempts with both humans and monkeys to demonstrate mirror reversal in interhemispheric memory transfer have failed [15]. That is, if a visual stimulus is presented to one hemisphere and the person or monkey is required to match it with a stimulus presented to the other hemisphere, the two hemispheres invariably match the stimuli accurately. They do not equate the stimulus in one hemisphere with its mirror image in the other hemisphere, as would be predicted from the Corballis and Beale idea of 'inter-hemispheric image reversal'.

Finally, a general objection to both Orton, and Corballis and Beale, is that the existence of a topographic representation of a stimulus ('a picture') in the brain, whether veridical or reversed, does not constitute an explanation of perception. 'Seeing is an interpretive process not a representational one' [16].

In summary, the Mach–Orton–Corballis hypothesis that mirror-image confusion derives from the symmetry of the body and brain does not work. Neither Orton's 'incomplete dominance' nor Corballis's 'memory reversal' fits the known facts.

III. AN EVOLUTIONARY HYPOTHESIS

If the symmetry of the body cannot explain mirror-image confusion, what can? We propose that the answer lies in the nature of the world and the evolution of the vertebrate visual system within it.

The selective pressure of evolution made it advantageous for the visual system to be able to perform certain types of visual processing while other types were unnecessary for survival. In the natural world there are never any mirror images that would be useful for an animal to distinguish. Indeed, with two exceptions, there are virtually never any mirror images at all. One exception is the two sides of a face or, more generally, the two sides of another bilaterally symmetrical animal. But here the two sides are aspects of the same thing, and it would be more adaptive to treat them as the same—not to distinguish them. Another exception is that a silhouette viewed from the back is the mirror image of the same silhouette viewed from the front. Again it would be adaptive to equate, not distinguish, these mirror images. In other words, we propose that the confusion of mirror images is not a "confusion" but an adaptive mode of processing visual information. In the natural world the only mirror images that ever occur are aspects of the same thing and therefore need not be distinguished. Rather, it is adaptive to treat enantiomorphs as equivalent to each other. Rather than the confusion of mirror images we can speak of their perceptual equivalence.

To summarize our argument, mirror images are not confused because of the symmetry of the brain. Rather, mirror images are treated as equivalent because in the natural world mirror images are almost always aspects of the same thing.

Fig. 6. 'Francis I Offers His Heart to Eleonore of Austria' by an anonymous French master (ca. 1536) [9]. *Note that two Ns and two Ss are reversed in the print. Letters in the block for this woodcut should have been incised originally in reversed form. Shapiro* [25] *observed that S and N are often reversed in early Medieval Latin inscriptions as they are by children and unpracticed adults.*

IV. READING, MIRROR IMAGES AND DYSLEXIA

The perceptual equivalence of mirror images poses a problem only for humans and only when, for example, they have to learn to distinguish *b* from *d* and write *s* not *ƨ* in the Latin alphabet. Then children must learn to overcome the natural mode of processing that evolution built into the brain, namely the perceptual equating of mirror images. On this view, mirror-image confusion is not unique to childhood except in the sense that it is as a child that a person usually has to overcome it. Thus, we would expect that non-literate adults should show the same confusion as children. Corballis and Beale inadvertently confirm our prediction in reproducing the medieval woodcut shown in Fig. 6.

Reading is a complex skill, and children may have difficulty in learning to read for a great variety of reasons including poor instruction, antagonism between cultures of school and home, sensory and neurological disorders, impaired language development, emotional disturbances and mental retardation. However, there is a small proportion of children for whom none of these conditions is present and yet who have severe and persistent difficulty in learning to read. Their condition is known as *developmental* or *specific dyslexia* or more simply 'reading failure of unknown origin'. Specific dyslexics are children of normal intelligence, vision, hearing, motivation and oral language development who have inexplicable reading problems. These dyslexics can be taught to read eventually, but difficulty in reading, spelling and learning foreign languages usually persists into adulthood [17].

Reversal of letters in place (*b* and *d*), reversal of letters in a word (*on* for *no*) and failure to progress consistently from left to right are common errors in learning to read and write. However, they are even more common among dyslexic children. Although not universal, mirror reversals and left-right difficulties appear to be the principal distinguishing features of specific dyslexics other than their reading disability [17, 18]. Can our explanation of mirror-image confusion also help explain specific dyslexia? Before suggesting how it may, it will be useful to review the difference between the left and right sides of the brain.

It is now well established that the two hemispheres of the human brain are each specialized for different psychological functions [11]. In virtually all right-handed people the left hemisphere is specialized for language. Therefore it is often termed the *dominant* hemisphere; but, strictly speaking, it is dominant only for language [19]. The right hemisphere is not just a non-linguistic version of the left. Rather, the right hemisphere is specialized for and better than the left hemisphere at a range of perceptual functions that do not involve language. These include visual matching, memory for abstract designs, copying and drawing, face recognition, construction of block designs and map-reading. It seems likely, therefore, that the perceptual equating of mirror images is also a right-hemisphere function [20].

Thus, specific developmental dyslexia may not reflect a deficit or dysfunction. Rather, we suggest it may indicate a relatively greater importance or dominance of the non-language hemisphere (the right hemisphere in right-handers). This would result in slower acquisition of reading, not only because reading is a left-hemisphere (language) skill but because mirror-image equivalence would be particularly strong or 'good'. A strong tendency to treat mirror images as equivalent would manifest itself in reversal of individual letters, in reversal of the order of letters in a word, and reversed scanning of phrases and lines: all classic symptoms of developmental dyslexia. According to this view, specific dyslexics should be superior to normal children on those perceptual, and perhaps artistic, skills that do not involve language, with one exception. The exception is in the discrimination of mirror images: On such tasks they would be much worse than normal children since we are postulating that mirror-image equivalence ('confusion') signifies the predominance of the nonlanguage hemisphere.

The repeated reports that dyslexics are unusually artistic and better at drawing even before their reading disability manifests itself support this interpretation [21]. Unfortunately, there are very few studies that provide an adequate test of our hypothesis, because most are directed toward looking for deficits rather than superiorities among dyslexics. Furthermore, when perceptual abilities are examined, the results of perceptual tests dependent on language or on right-left discrimination are usually reported together with the results of tests that are not; we would expect dyslexics to be superior only on the latter ones. Finally, most studies of dyslexics include children who clearly have other difficulties than in learning to read, or they fail to compare these children with children of matched intelligence, age and background. Thus it is not surprising that among studies of visuo-perceptual abilities in dyslexia, most find dyslexics 'unimpaired', a few find deficits, and only a very few find superiorities [17, 18, 21].

If correct, our suggestion that specific dyslexics are superior at a variety of non-language related perceptual skills may be relevant to techniques of teaching reading. In any case, to view dyslexics as potentially superior in so many other skills than reading and to encourage and develop this potential would certainly reduce the devastating emotional and social consequences of reading disability, which often are more crippling than the disability itself. It may be both more accurate and more helpful to view specific dyslexia as a difference rather than a deficit.

V. LEFT, RIGHT AND ART

Gravity provides humans with an unambiguous basis for distinguishing up and down. Although Wu's cobalt-60 experiments revealed standards for labeling left and right, left and right are still confusing mirror images in physical space. Are differences in pictorial space confusing in the same way? Is there a left and right in pictorial art, and, if so, are they related to left and right in the brain?

Aestheticians [22–26] have frequently asserted that left and right in a picture are absolutes. Wölfflin and Gaffron have both emphasized, for example, that mirror-reversing a painting often drastically alters its meaning; thus they claimed that many of Rembrandt's etchings can be understood only by looking at their mirror reverse. For at least some paintings, this reversal effect is indeed striking. For example, mirror-reversing Janssens's 'Reading Woman' (Fig. 7) clearly alters the composition [22]. Similarly, the effect of reversing Brueghel's 'Parable of the Blind' is to change the impression of the painting so that 'instead of

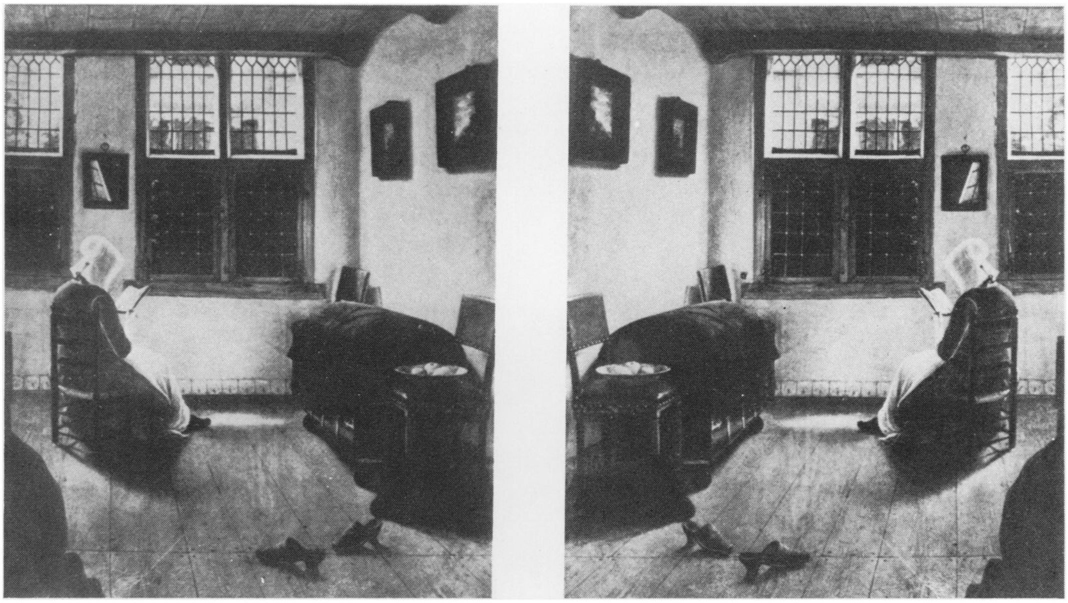

Fig. 7. 'Reading Woman' by P. Janssens (1640–1700), Alte Pinakothek, Munich. Left: *Veridical reproduction.* Right: *Mirror-image reproduction. The viewer's position relative to the perspective of the floor boards seems to change in these two versions. In the original, the viewer stands naturally at the woman's back looking over her shoulder; in the mirror-reversed version the viewer must change position to effect such an identification. In the veridical version the woman, in the left pictorial space, is important; in the mirror-reversal her slippers assume salience out of proportion, i.e. they are nearer and more conspicuous. Indeed pictorial depth is greater upon mirror-reversal. Gaffron* [23] *suggested that these and other phenomenal differences arising from mirror-reversal evidence the existence of an unconscious central visual process or glance curve in pictorial perception. Thus, the slippers assume great prominence and appear closer, because they stand at the head and in the path of the glance curve.*

tumbling into the ditch after their leader, [the blind men] seem to be pressing upon him' [23].

If, as aestheticians say, mirror reversal so changes the meaning of a painting, why have so many artists, from Raphael [4] and Rembrandt to Munch [23], remained apparently indifferent to the reversal of their originals when reproduced as prints or tapestries? And why conversely did a few, such as Dürer and Van Gogh, take great care to etch originals in their mirror image?

In fact, objective studies involving a number of observers and different paintings have lent little support to the generality of the claims of art historians that mirror-reversing paintings consistently changes the content or tone of the original. For example, when children and young adults were asked to tell whether they preferred the original or the mirror-image views of a series of classical, e.g., Raphael, Rubens, and Rembrandt, or modern paintings, e.g., Mondrian, Picasso, and Degas, preference for the original view was slight or non-existent [27]. Similarly, in two other studies subjects could not accurately remember the left-right orientation of a set of representational pictures [28].

A possible explanation for the failure of experimental psychologists to find the perceptual differences between paintings and their mirror reverses claimed by aestheticians might be that the psychological experiments involved collections of both symmetrically and asymmetrically organized compositions; by contrast aestheticians exemplify their point with highly asymmetric paintings. Highly asymmetrical paintings, with marked perspective and lighting differences between the two sides (such as Fig. 7), clearly do alter on reversal. However, for naive adults viewing most paintings, as for children learning to read or for octopuses discriminating obliques, mirror images tend to be seen as equivalent. In all these cases the confusion or equivalence of mirror-reversed images represents a fundamental mode of visual analysis originating in organic evolution.

Independent of the difficulties people usually experience in telling left from right in nature or detecting mirror-image reversals of works of art, there appear to be verifiable differences associated with the left and right halves of physical space and pictorial space. Many aestheticians [22, 23, 26] have suggested that the right visual field or objects located there tend to be perceived as heavier, larger, more distant, brighter and more conspicuous, but less textured and less clear, while the left pictorial field or objects located there tend to have the opposite attributes. Several of these claims have been verified experimentally. Specifically, under controlled conditions with a number of subjects, objects on the left have been found to appear closer [29] and clearer [30] and content on the right to appear heavier [31].

VI BRAIN MECHANISMS OR ARTISTIC CONVENTIONS?

Asymmetries of pictorial space could arise from asymmetries of the brain or from cultural conventions. We suggest that both contribute to the anisotropy of art but in different ways.

As discussed above, the left hemisphere of the brain is principally concerned with the perception and production of linguistic material, and the right cerebral hemisphere is principally concerned with the perception and discrimination of nonverbal and spatial material [11]. When visual input is strictly lateralized, and the eyes are not free to roam, the right half of visual space is processed primarily by the left hemisphere, and the left half of visual space is processed primarily by the right hemisphere (Fig. 5). Strict asymmetric input is, of course, not the case in artistic experience, since one does not just fixate the center of a painting. However, both Kinsbourne and Gur [32] have demonstrated that visuo-spatial thinking and verbal thinking (or anticipation of these types of thinking) activate processes in the right and left hemispheres respectively and, at the same time, excite correspondingly lateralized eye movements. Apparently, differential processing of information between the hemispheres is so basic as to maintain lateral biases even in the absence of strictly lateralized input. Hence the importance of cerebral lateralization to art.

Anisotropies of visual space that are universal in humans probably reflect the influence of lateralized brain functions rather than cultural convention. One artistic asymmetry that appears to be universal in this way is profile orientation. Portraits are rarely full-face; one study found that of 1474 painted portraits produced in Western Europe between 1500 and the present, a majority face leftward [33]. Similarly, right-handed children and adults of both sexes have a strong tendency (74% of 9874) to draw profiles facing leftward [34]. This was found in the U.S.A. and Norway (where reading is from left to right), Egypt (where reading is right to left) and Japan (where reading is from top to bottom and right to left). By contrast, left-handed children were equally likely to orient their profiles in either direction, presumably reflecting the heterogeneous nature of left-handers and demonstrating that profile orientation is not a simple function of how the hand holds a pencil. Leonardo da Vinci, perhaps the most famous left-handed artist, preferred to draw right-facing profiles. An examination of the profiles in the Dover edition of Leonardo da Vinci's *Notebooks* [35] shows that most of the profiles therein face right (Fig. 8).

Profile orientation appears to be a function of laterality, not direction of reading, age, or sex. When a face is fixated centrally, the half of the face in the left visual field is processed by the right hemisphere (Fig. 5). As noted above, face recognition is a right-hemisphere function [11] and, when right-handed people look at the two halves of a front view of a face, the half of the face in the left visual field looks much more 'like the person' than the other half [36]. Thus the tendency for portraits to locate profiles in the left visual field presumably reflects the fact that facial information there would be perceived more

Fig. 8. Constellation sheet depicting Leonardo da Vinci's family and his earliest self-portrait (ca. 1469). (From the Royal Library at Windsor, No. 12, 276 v.)

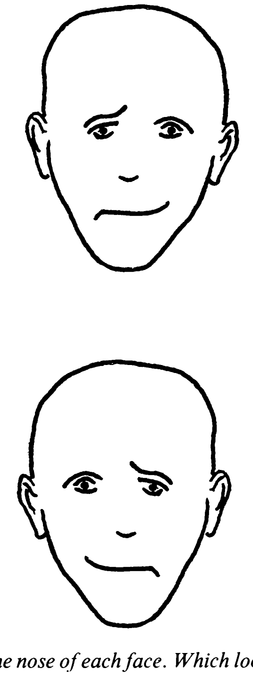

Fig. 9. Stare at the nose of each face. Which looks happier? Jaynes found that most right-handers choose the bottom face with the smile in their left visual field, presumably because the smiling side is processed by the right hemisphere on central fixation. [© J. Jaynes, *The Origin of Consciousness in the Breakdown of the Bicameral Mind* (Boston: Houghton Mifflin, 1977)].

readily and accurately by the majority of people (i.e., right-handers). Similarly, as shown in Fig. 9, it is the expression on the half of the face in the left visual field that usually determines the right-handed viewer's impression of it.

In contrast to profile orientation, other aspects of visual anisotropy appear to reflect cultural conventions. Wölfflin [22], and others [27, 26], have suggested that individuals typically enter a picture at the left foreground and proceed along a specified path or 'glance curve' into the depth of the picture and over to its right-hand side [22, 23]. They point out how this direction scan lends an aesthetic dimension of movement in graphic art. Movement from left to right in a painting is easier and faster, while movement from right to left is slower and perceived as having to overcome resistance. The former signals attack or approach; the latter withdrawal: in addition, the / diagonal is often associated with ascent and triumph, while \ is associated with descent and defeat. Poussin's 'The Rape of the Sabine Women' (Fig. 10) epitomizes the use Western artists have made of these associations. The painting is a single dramatic frame out of an episode of the Roman legend. Fig. 11 indicates the diagonals at work in the painting. The strong diagonal (Fig. 11, bottom) begins at the left with the entrance of the Roman fasces-bearer below (and Romulus above) and is continued in the Roman rout of the Sabines which proceeds off the canvas to the right. The weak diagonal (Fig. 11, top), mainly focused in the father's futile attempt to save his daughter's honor in the lower right, is overwhelmed. These crossed diagonals represent opposing forces and express the theme of conflict and counter-conflict in a classical manner (the theme originally derives from the metopes in the Parthenon); they inwardly organize a scene otherwise emotionally explosive and chaotic.

Wölfflin believed that the left-to-right glance curve represented a fundamental aesthetic vector. However, the glance curve in Oriental art appears to be in the opposite direction. Compare the directional selectivity of the Poussin with that evident in a detail from a Chinese handscroll—opened and read from right to left (Fig. 12). Here the direction of viewing first to the lower right and then towards the upper left is compelling.

Similar aesthetic vectors seem to operate in stage direction and audience expectation in the theater. According to Dean [37], the right stage (audience left) in Western theater is strong and elicits audience attention, so, as the curtain rises at the beginning of an act, the audience can be seen to look to the left front. In Chinese theater, contrariwise, the important positions are to the audience right. Thus the direction of the glance curve in both painting and theater appears to be a cultural convention, presumably related to the direction of reading, left to right in the West and right to left in the East. As Gaffron [23] says explicitly, 'we "read" a picture in a certain way just as we read a page of a book'.

The term 'glance curve' may be a misnomer, however, since studies of eye movements across both Eastern and Western pictures do not reveal glance curves in either direction [38]. Rather such studies suggest that the eye roams over a picture in an arbitrary manner, only stopping to rest on salient features. The glance curve may be some kind of covert cognitive scanning with its direction set by reading habits. Or, alternatively, it may reflect a cultural organizing principle implicit in graphic art. Whether in observers or in pictures, conventions like the glance curve prevent representational art from approaching excessive abstraction with its multiple and ambiguous points of view [39]. If there

Fig. 10. 'The Rape of the Sabine Women' by N. Poussin (ca. 1639). (Metropolitan Museum of Art, New York, N.Y.) (See Fig. 11).

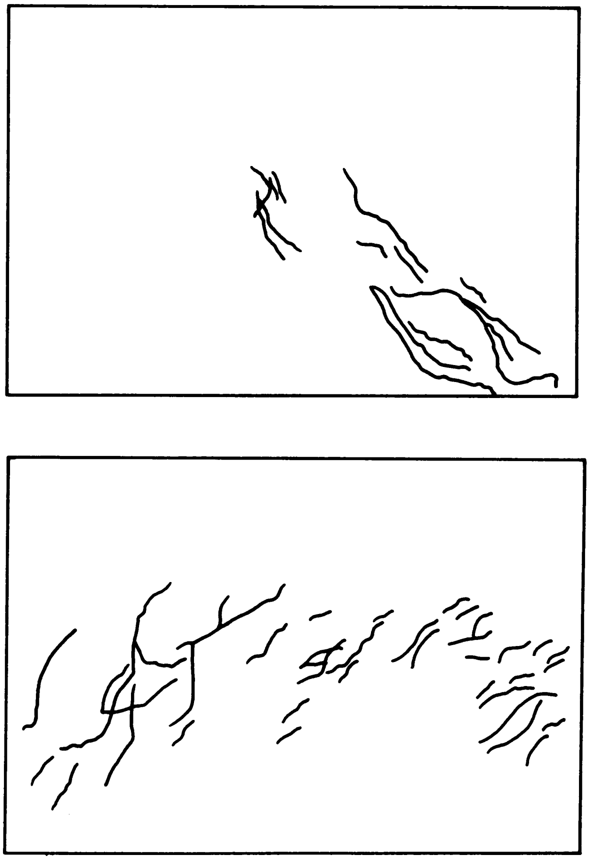

Fig. 11. (Top) The 'weak' diagonal (lower right to upper left). (Bottom) The 'strong' diagonal (lower left to upper right). (See Fig. 10)

Fig. 12. 'Twin Pines against a Flat Vista' by Chao Meng-fu (1254–1322). (Metropolitan Museum of Art, New York, N.Y.) *Detail of a Chinese handscroll. Such handscrolls typically show dominant diagonals that follow the direction they are opened and read—right to left.*

were no such conventions about left and right to show the way, artists and observers, like children, might be confused as to how to view a picture.

We wish to dedicate this essay to Hans-Lukas Teuber, late founder of the Department of Psychology and Brain Sciences, Massachusetts Institute of Technology. We thank H. Bornstein, R. Desimone, G. E. Gross, R. E. Peierls, L. Seacord and T. Sejnowski for their helpful criticisms. This work was supported by the Spencer Foundation.

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1. Leibnitz's critique of Newton occurred in his running controversy with Samuel Clarke, an English philosopher and divine acting as Newton's spokesman. See particularly Leibnitz's third letter to Clarke in M. Morris, ed. and Trans., *Philosophical Writings of Leibnitz* (London: J. M. Dent, 1951).
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