

REVIEW ARTICLE

The neurology of kinetic art

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Credo (manifesto of physiological facts)

All visual art must obey the laws of the visual system.

The first law is that an image of the visual world is not impressed upon the retina, but assembled together in the visual cortex. Consequently, many of the visual phenomena traditionally attributed to the eye actually occur in the cortex. Among these is visual motion.

The second law is that of the functional specialization of the visual cortex, by which we mean that separate attributes of the visual scene are processed in geographically separate parts of the visual cortex, before being combined to give a unified and coherent picture of the visual world.

The third law is that the attributes that are separated, and separately processed, in the cerebral cortex are those which have primacy in vision. These are colour, form, motion and, possibly, depth. It follows that motion is an autonomous visual attribute, separately processed and therefore capable of being separately compromised after brain lesions. It is also one of the visual attributes that have primacy, just like form or colour or depth.

We conclude that it is this separate visual attribute which those involved in kinetic art have tried to exploit, instinctively and physiologically, from which it follows that in their explorations artists are unknowingly exploring the organization of the visual brain though with techniques unique to them.

Introduction

Physiologically speaking, kinetic art represents a reductionist approach which emphasizes motion and de-emphasizes both form and colour or at least renders them insignificant. Using it, artists have, almost certainly unknowingly, tried to obtain aesthetic effects by stimulating optimally only a limited number of visual areas in the cerebral cortex, specifically those concerned with visual motion. Kinetic art therefore provides fertile ground on which to begin an exploration of the relationship between the physiology of visual perception, brain activity and the aesthetic experience of visual art. To study that relationship is to undertake an absorbing and yet formidable task. Aesthetics must involve a great deal more than the stimulation of specific visual areas —learning, memory, cultural upbringing, individual variation and much else besides will play a role. We are therefore aware that even our timid and limited approach may open us to possible ridicule. Many might ask whether enough is known about the physiology of the brain to make this the right time to undertake such an enquiry; others might think that aesthetic experience is too complex a matter to be reduced to specific brain pathways and areas —they might want to remind physiologists, as one painter did, of Gustave Moreau's admonition to modern artists that 'Vous voulez

simplifier les choses!' (Balthus, 1991). In spite of these difficulties, we believe that the functional organization of the visual cortex is now known in sufficient detail for us to be able to relate the perceptual effects of viewing kinetic art directly to the activity that occurs at relatively early levels of the visual pathways, specifically in the specialized visual areas of the cerebral cortex. Although we cannot, of course, trace a global relationship between brain activity and aesthetic experience in visual art in the present state of knowledge, implicit in our approach is the supposition that physiological stimulation of specific visual areas can create aesthetic experiences, which is not the same thing as saying that the aesthetic experience that results from kinetic art is due solely to the activity of the areas which we highlight below. Nor do we imply that stimulation of one area alone, or of a limited number of visual areas, yields a richer artistic experience than the stimulation of many different visual areas simultaneously.

Of necessity, some of the conclusions which we shall derive, though based on fact, will have to be tentative and speculative in so far as we are probing a topic that has never been approached before and is consequently still in its beginnings. When we speak of kinetic art, we mean art in which objective

motion plays a dominant part or one in which the perception of motion is strongly induced by a static figure. We are not concerned with the representation of motion in static terms or of the suggestion of motion by various static and graphic devices, an effort pursued since the earliest days by artists of all cultures, although that in itself constitutes an important and interesting topic. Our only interest in this consists of the period when artists were beginning to flirt with the idea of using actual motion without in fact doing so, since they were still exploring ways of incorporating it into their work. An excellent example is provided by Marcel Duchamp's (1914) notes for his work, *La mariée mise en nu par ses célibataires, même* (*The Bride Stripped Bare by her Bachelors, Even*), which we discuss below. Nor are we concerned with the social and philosophical implications that kinetic artists have sometimes ascribed to their work or to their views on art. For example, Kosice's view that there should be a profound connection between movement and 'the increasingly humane qualities of modern social life' (Popper, 1968) is of no concern to us here, although the point itself is interesting, in that it attributes to social and political forces what is essentially a physiological process. Equally, the profound psychological insight into past traumas that some have seen in the kinetic sculpture of Rebecca Horn or the psychotherapeutic value that Schöpfer sees in movement (Bourriaud, 1991) or the sexuality that some see in Pol Bury's slowly moving protuberances, against which those with weak cardiac conditions have been warned (Cabanne, 1991), are not topics we shall enter into. Our interest is therefore limited to discussing the relationship between overt movement in kinetic art, stripped of all its intellectual associations, and the physiology of the brain, and to tracing the major steps in the development of kinetic art which tailored it more and more to minimalist physiological activation of the cerebral visual areas. We do not therefore provide an exhaustive review of kinetic art but trace only those moments which seem to us to be of importance in the unacknowledged process of physiological discovery which artists unknowingly indulge in. Implicit in our view is the more general supposition that, when executing a work of art, the artist unknowingly undertakes an experiment to study the organization of the visual brain. We thus aim to show in this essay that, just as physiologists have managed to identify visual areas in the cerebral cortex specialized for visual motion so artists, through their experiments, have unknowingly developed an art form seemingly tailored for an optimal stimulation of these visual areas.

Part I: The physiological identification of a cortical specialization for visual motion

The pivotal role of area V5 in kinetic art

Our interest in kinetic art stems from the discovery that there is a large number of separate visual areas in the cortex surrounding the primary visual area (V1) of the macaque monkey brain (see Zeki, 1974a, 1978a, for reviews) and that one of these, area V5, is specialized for visual motion (Zeki, 1974b; Van Essen *et al.*, 1981; Maunsell and Van Essen,

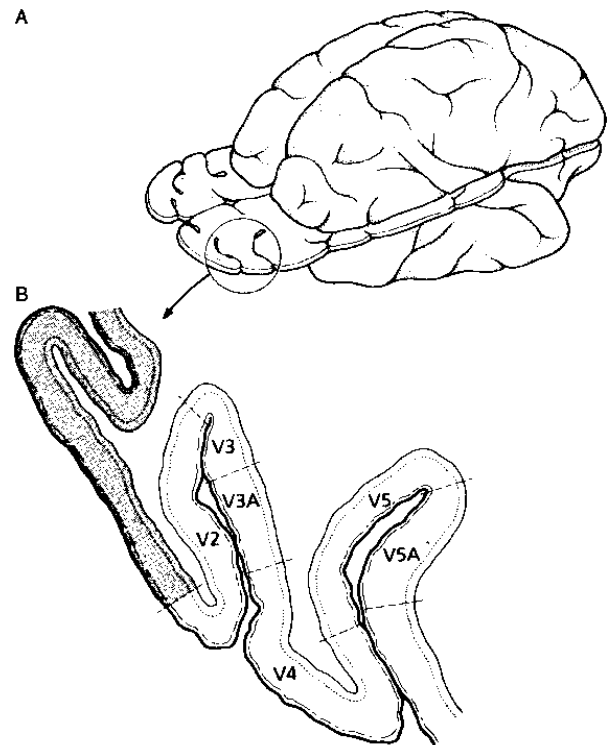


Fig. 1 Reconstruction of a horizontal section, taken through the brain of the macaque monkey at the level indicated, to show the positions of area V5 and area V3. Area V1 is shaded.

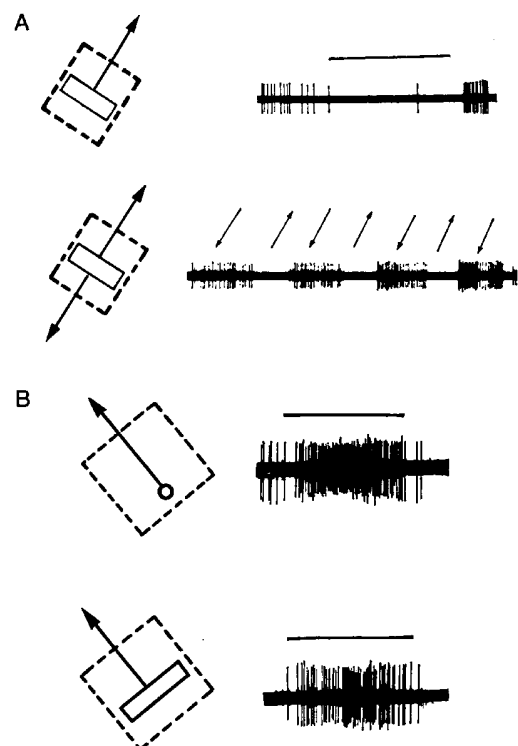


Fig. 2 The responses of a directionally selective cell in area V5. **A** shows that the cell responds to motion in one direction but not in the opposite, null, direction. **A** shows a directionally selective cell that prefers spots to bars. (From Zeki S, *J. Physiol* 1974; 236: S49–73.)

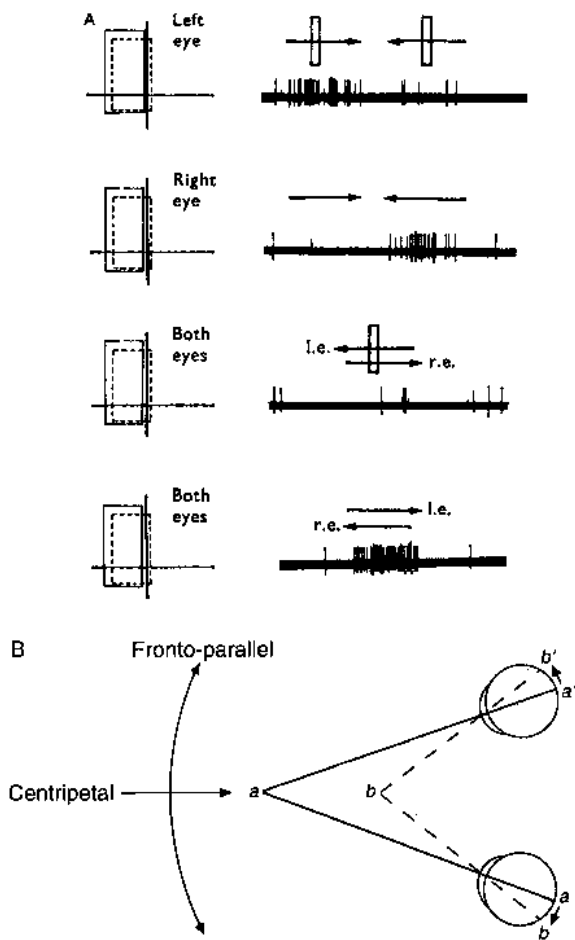


Fig. 3 **A**, the responses of a directionally selective cell in area V5 to stimulation through each eye in turn. The cell responded to motion towards the left when stimulated with the right eye alone open and towards the right when stimulated through the left eye alone open. **B**, a schematic drawing to show that, with both eyes open, a cortical cell responding to opposite directions of motion through each eye would signal motion towards the organism (From Zeki S, *J Physiol* 1974; 236: S49–73.)

1983a; Albright, 1984) (see Fig. 1). The cells of V5 are unresponsive or very weakly responsive to stationary visual stimuli. Instead, the great majority are directionally selective, responding to motion of the visual stimulus in one direction and not in the opposite, null, direction; most give their optimal response to spots of light and are not concerned with the form (orientation) of the stimulus (Fig. 2). As well, virtually all are indifferent to the colour of the visual stimulus. A small percentage respond to motion in any direction and hence their true purpose might be assumed to signal the presence of motion *per se* (Zeki, 1974b). Different cells have different preferences for the speed of motion, some responding to only very slow while others to very fast motion; the majority respond to moderate speeds of $\sim 32^\circ/\text{s}$ (Maunsell and Van Essen, 1983). The overwhelming majority of cells are equally well driven when stimulated through either eye and their properties as studied through one eye are very nearly identical to their properties when studied through the other eye (Zeki, 1979).

There is, however, one group of cells within V5 which have different properties when tested through the two eyes (Zeki, 1974c). A cell may, for example, respond to motion towards 3 o'clock when tested through the right eye and towards 9 o'clock when tested through the left eye (Fig. 3). Translated into three-dimensional space, such a cell would be capable of signalling motion towards the organism; other, similar, cells are specialized to signal motion away from the organism. The directional selectivity of some cells in cortical areas adjoining V5 depends upon the depth of the stimulus with respect to the fixation point (Wurtz *et al.*, 1990). Kinetic art has a frontoparallel as well as centripetal and centrifugal components, as can be ascertained at a glance by examining the mobiles of Calder or the kinetic constructions of Tinguely or those of Moholy-Nagy where movement occurs in all planes. In short, all the experimental evidence shows that V5 is specialized to detect motion in both the fronto-parallel and egocentric planes. This conclusion is reinforced by the observation that micro-stimulation of groups of V5 cells with particular directional preferences produces a corresponding bias in the monkey's perception of the direction of motion (Newsome *et al.*, 1990). The human homologue of V5 has now been identified (see below) and it is certain that it is prominently involved in the perception of visual motion and therefore in kinetic art.

In the monkey, in addition to V5, there is another and separate visual area in the cortex surrounding V1, area V3 (Cragg, 1969; Zeki, 1969; Van Essen *et al.*, 1986; Gattass *et al.*, 1988). The great majority of its cells are orientation (form) selective. But their responses to static oriented lines are weak, the cells responding best when the oriented lines are in motion, often in one direction (Zeki, 1978c; Burkhalter *et al.*, 1986; Felleman and Van Essen, 1987; Gaska *et al.*, 1988). Moreover, like the cells of V5, those of V3 are indifferent to the colour of the stimulus (Zeki, 1978b; Felleman and Van Essen, 1987). It is traditional to equate orientation selectivity with form because oriented lines and edges are so cardinal a feature of forms. Indeed, they themselves constitute elementary forms and have been prominent features of many paintings, especially those belonging to the Russian Constructivist school (see below). We make this equation with diffidence because a complex form such as a car, say, cannot be defined in terms of lines only and because we are still neurologically ignorant of the cortical machinery that is required and capable of generating such complex forms. Whatever that machinery, it is clear that, at the early levels of the visual cortex with which we are concerned here, cells do not respond specifically to complex forms such as cars or houses. Rather, the kind of relatively simple responses found in the cells of area V3 must be used subsequently to activate cells with capacities to register more complex forms. But the neurological literature nevertheless distinguishes between the perception of static forms and the same forms when they are in motion (dynamic forms). Patients with the syndrome of 'visual object agnosia' are commonly, though not always, unable to recognize objects when they are static but able to do so when the same objects are set in motion (see Zeki, 1993,

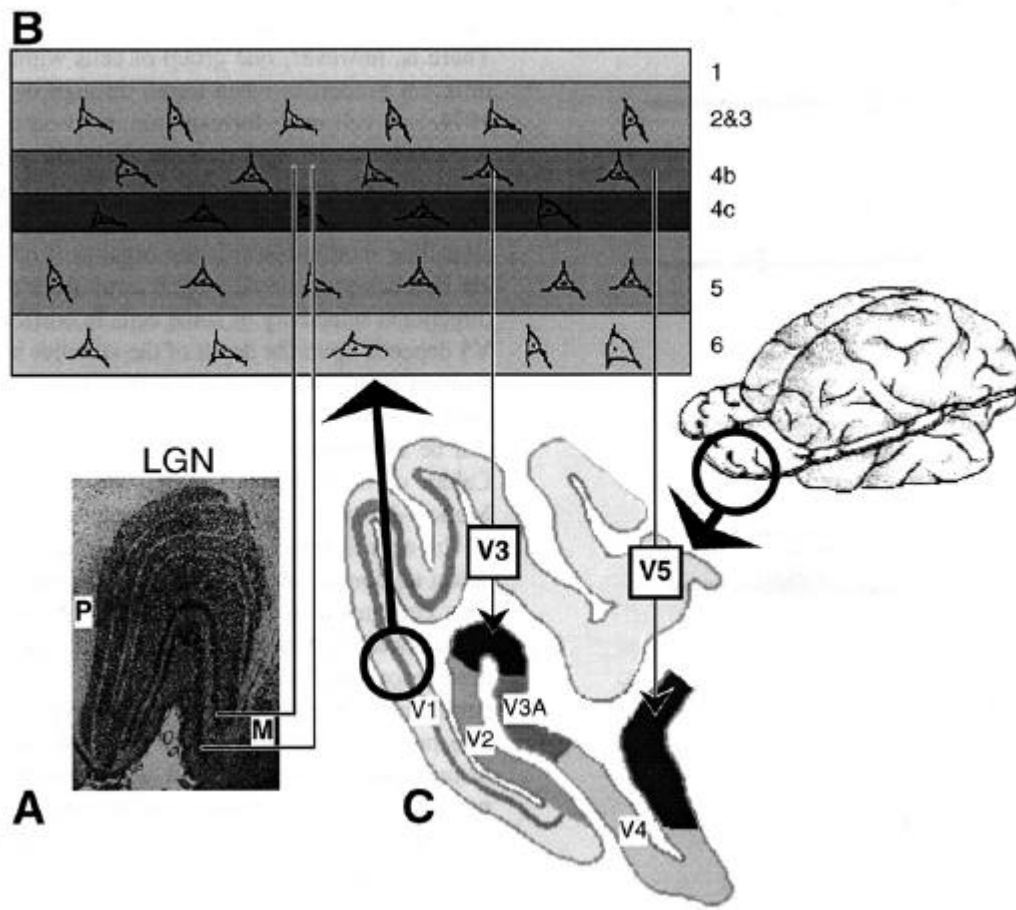


Fig. 4 A reconstruction of the projections from the lateral geniculate nucleus (LGN) to the visual cortex. **A** is a coronal section through the LGN to show the upper four or parvocellular (P) layers and the lower two or magnocellular (M) layers. The output of the latter layers is relayed to layer 4b of V1, reconstructed in **a**, which in turn sends outputs to areas V3 and V5, shown here in a horizontal section through the brain (**c**), taken at the level indicated. For simplicity, many details have been omitted in this diagram.

for a review). Equally, some patients with cerebral lesions have difficulty in recognizing objects when defined by motion but can do so when they are defined by luminance (Regan *et al.*, 1992). This suggests that there is a different, and separate, representation for dynamic, as opposed to static, forms and for forms defined by motion as opposed to those defined by luminance in the human brain. We presume that V3 is well suited to play at least an initial role in the perception of dynamic forms, that is to say forms which are in motion (Zeki and Shipp, 1988; Zeki, 1990b) and, given the intimate perceptual link between dynamic forms and motion, it would be surprising if there were not a correspondingly intimate anatomical and functional link between V3 and V5. In fact, area V3 has a complex anatomical relationship with area V5 (Maunsell and Van Essen, 1983b; Ungerleider and Desimone, 1986; Zeki, 1990a). One might expect to find, therefore, a human homologue of V3 which is broadly similar, though not necessarily identical, in its physiological organization to monkey V3 and therefore more involved in dynamic forms. Because dynamic forms, whether in the mobiles of Calder or the kinetic sculpture of Horn, both of which contain edges of different

orientations in motion, constitute such an elemental aspect of kinetic art, such an area would also be expected to play a pivotal role in it. Both V5 and V3 have satellite areas which share their broad physiological properties although they are distinct cortical areas (Zeki, 1978c; Desimone and Ungerleider, 1986; Zeki, 1990a; *see* Wurtz *et al.*, 1990, for a review). We therefore speak of the V5 complex and the V3 complex. There is evidence that, in the human brain, the satellite areas of V5, at least, may be important in the generation of the illusory motion that is an important feature of some of the more recent works of kinetic art (*see below*).

The segregation of visual motion signals at early levels of the visual pathways

The de-emphasis of colour in V3 and V5 is not surprising, since they share a common retinal input which is itself largely unselective for colour. This input is usually referred to as the M input because it is derived principally from the lower two, magnocellular (M), layers of the lateral geniculate nucleus, the relay nucleus linking the retina to V1. The physiological

characteristics of the M layers make them suited to register motion in the field of view (Dreher *et al.*, 1976; Lee *et al.*, 1979; Derrington *et al.*, 1984). The output from the M layers is channelled to V5 and to V3 through layer 4B of V1, both directly and through a specific subcompartment of an adjoining visual area, V2 (for a review, *see* Zeki and Shipp, 1988) (Fig. 4). Two prominent physiological types of cell are found in layer 4B of V1, those which are orientation (form) selective and those which are orientation (form)-plus-direction (motion) selective (Dow, 1974; Hawken *et al.*, 1988). The latter project to area V5 and the former to V3, although some of the directionally selective cells of layer 4B may project directly to area V3, given that cells in V3 are often directionally selective as well (Zeki, 1978b; Felleman and Van Essen, 1987). The projection from layer 4B of V1 to both V5 and V3 is convergent (Zeki, 1971). The consequence of this is that the cells of V3 and V5 have larger receptive fields than their counterparts in V1, thus making them responsive to larger parts of the field of view than the cells of V1 (Zeki, 1974a, 1978c; Gattass and Gross, 1981; Albright and Desimone, 1987). This is an important point to bear in mind when considering the interrelationships between the areas during the perception of visual motion.

By contrast, the upper four, or P layers, of the lateral geniculate nucleus have somewhat different properties and cortical destinations, many of their cells being selective for the wavelength of the stimulus (Wiesel and Hubel, 1966). The output from them is channelled to area V4 through layers 2 and 3 of V1, both directly and through another subcompartment of area V2 (Zeki and Shipp, 1989; Nakamura *et al.*, 1993) (Fig.4). Hence, even at early levels of the visual system, there is some degree of segregation which tends to concentrate cells concerned with visual motion in specific layers of area V1 and, by virtue of the specific outputs of that layer, in specific areas of the prestriate visual cortex, namely V3 and V5. We do not, however, wish to give the impression that the input to areas V3 and V5 is derived from the M layers of the lateral geniculate nucleus only. There are many opportunities for the M and P derived subdivisions of V1 (and the contiguous area, V2) to interact (*see* Zeki and Shipp, 1988). Moreover, the motion of a coloured stimulus may be detected, at least in part, because of the difference between the colour of the stimulus and the colour of the background. It is therefore our view that a cortical area such as V5 will use information derived from any source to undertake its function, in this case that of detecting motion (Zeki and Shipp, 1988). This is consistent with the finding that many cells of V5 will continue responding even if the moving stimuli are equiluminous with the background, that is differ from the background in wavelength composition alone (Saito *et al.*, 1989). The critical requirement for the activation of V5 cells is the presence of motion.

Human V5 and kinetic art

One might expect that if an area similar to V5 exists in the human brain, it would be optimally responsive to any visual

stimulus in which motion predominates, which is of course what happens in kinetic art. In fact, recent studies using the technique of positron emission tomography (PET), which measures changes in regional cerebral blood flow (rCBF) when humans undertake particular tasks, have shown that there is indeed a functional specialization in the visual cortex of the human brain and that there is a specific visual area situated outside the territory of the primary visual cortex (area V1) which specifically shows a change in rCBF when humans view a visual stimulus in motion (Zeki *et al.*, 1991; Watson *et al.*, 1993). Changes in rCBF are indicative of synaptic activity within an area (Raichle, 1987); one can therefore conclude that the relevant visual area, human V5, is specifically active during visual motion stimulation (Fig. 5). Of course, V1 itself and the adjoining visual area, V2, are also active when humans perceive visual motion, since it is V1 which receives the signals from the retina and distributes them to the specialized visual areas, both directly and through V2. But, because they distribute all visual signals to the specialized visual areas, V1 and V2 are active with all types of visual stimulations, not just kinetic stimuli (Zeki *et al.*, 1991).

It is important to be quite clear about what the PET results demonstrate. Positron emission tomography is an essentially subtractive method—the activity in the brain when a subject views a given stimulus is subtracted from the activity when the same subject views another stimulus, identical in all respects to the first save only for the attribute being studied. Thus, for studies aiming to reveal the areas of the cerebral cortex especially concerned with visual motion, the pattern of cerebral activity obtained when subjects view an array of small stationary squares is subtracted from the activity obtained when the same subjects view the identical stimulus when it is in motion (Zeki *et al.*, 1991). When we say that areas V1, V2 and V5 are active during the perception of a visual stimulus in motion, we do not imply that all other visual cortical areas are silent, but only that these three areas are especially active and therefore more prominently involved in the perception of visual motion and, by inference, of kinetic art. The point is worth emphasizing for we are not pretending that other visual areas of the cerebral cortex are silent or are not active during kinetic stimulation, but only that area V5 is especially active and therefore especially involved in the perception of movement, without which it would be difficult, if not impossible, to perceive kinetic art. There is direct clinical evidence, reviewed elsewhere (Zeki, 1991), to show that area V5 is critical for the perception of visual motion in man, since lesions in it lead to the syndrome of visual motion blindness (Zihl *et al.*, 1983, 1991), a syndrome which is referred to as cerebral akinetopsia (Zeki, 1991). More recently, studies in humans have shown that the perception of visual motion can be transiently and reversibly compromised by direct magnetic stimulation of area V5 (Beckers and Hömberg, 1992).

We do not suggest that V5 is the terminal locus for the perception of visual motion or that V3 is the terminal locus for the perception of dynamic forms. The information about motion extracted by V5 must be made available to other systems. It

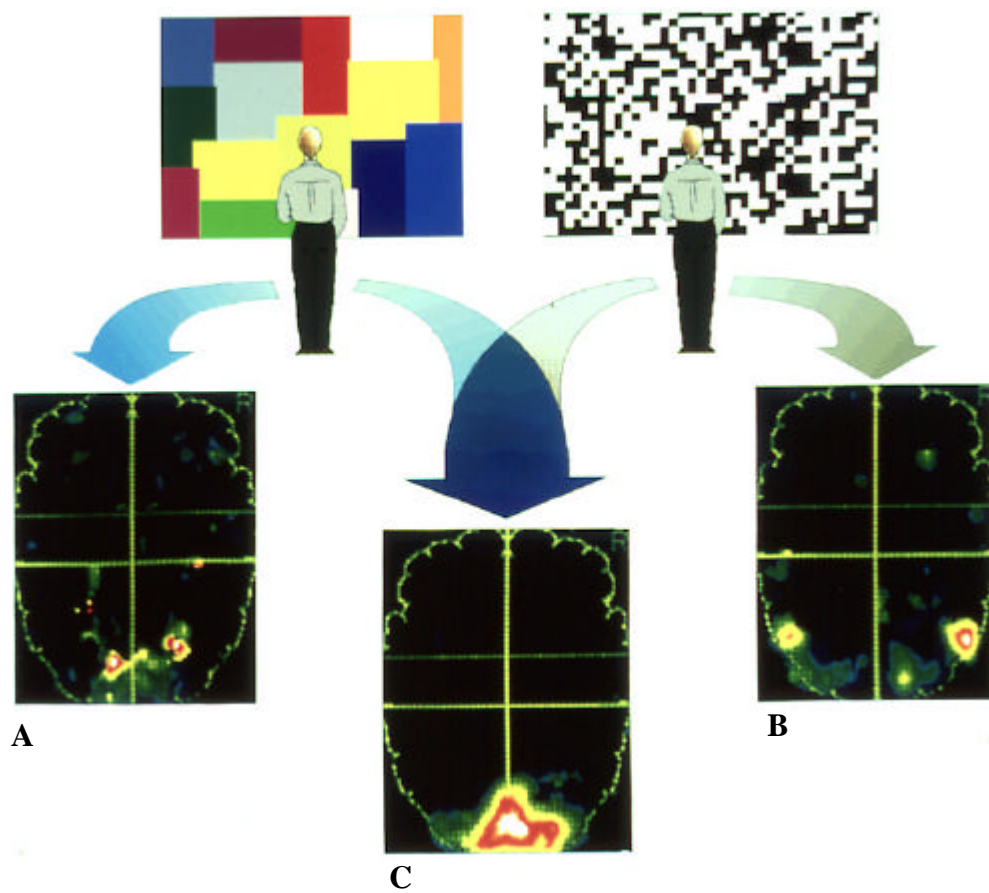


Fig. 5 The results of an activation study using PET to determine the position, in horizontal slices through the brain shown in **A**, **B** and **C**, of the most significant changes in rCBF when humans view an abstract colour scene (human V4, **A**) and a pattern of black and white squares in motion (human V5, **B**). Note the difference in the position of the two areas active with these different visual stimuli. Since both areas receive input from the primary visual cortex, V1, and the area adjacent to it, V2, the latter areas are also active but in both conditions of stimulation (**C**). (From Zeki S, La Recherche 1990; 21: 712—21.)

is not surprising to find that monkey V5 is not a terminal station for motion perception. Instead it acts as a sort of funnel, distributing motion signals to further areas, since it connects with many cortical areas, including the other subdivisions of the V5 complex and areas in the parietal and temporal regions of the brain (Ungerleider and Desimone, 1986; Zeki, 1990a). It is probable that the same is also true for human V5. These other cortical areas could play an important role in viewing kinetic art but what that role may be is difficult to tell at present.

Areas V1, V2 and V5 are not the only areas which are activated by the motion stimulus that we have used in our PET studies. Another area, which we consider to be the human equivalent of monkey V3, is always active with the kind of stimulus which we have used, presumably because it contains so many oriented edges (Watson *et al.*, 1993). The fact that every activation of area V5 involves a

concurrent activation of putative human area V3, suggests that they may be in close anatomical contact in the human brain, just as they are in the monkey. Moreover, it shows that both are important cerebral visual centres for the perception of motion *per se* or the perception of simple forms when these are in motion. In summary, all the available experimental and clinical evidence points to a critical role for human area V5 in the perception of visual motion and therefore of kinetic art and for a close linkage between it and area V3.

Here it is interesting to consider briefly the patient of Zihl, who suffers from the syndrome of akinetopsia, i.e. a specific motion imperception following cerebral lesions and whom we have studied recently (unpublished results). Although the lesions in this patient are extensive and involve white matter, they

invade the territory of area V5, as defined in our earlier studies (Watson *et al.*, 1993). Our brief psychophysical study of this patient showed that she was capable of some residual motion detection. With the stimuli which we used for the PET study, she was able to detect (i) the presence of motion and (ii) the direction of motion if it was in the four cardinal axes, that is 6–12 o'clock and 3–9 o'clock, but unable to detect the motion if it was in the diagonal axes (*see also Hess et al.*, 1989; Baker *et al.*, 1991). Therefore, in the PET study, we compared the rCBF in her brain when she was exposed to a stimulus in motion in the cardinal axes and to the same stimulus when it was stationary. The results showed that the activity in her prestriate cortex was restricted to parietal cortex, to putative area V3 and to a zone lying anterior and inferior to area V5, extending into the fusiform gyrus. The latter zone, which may be part of a broad zone of motion related visual cortex, distinct from V5 but intimately linked to it, was also active in some normal individuals in our earlier study, though the activity must have been relatively weak for it to disappear when the results from all subjects were grouped together (*see Watson et al.*, 1993). This would suggest that areas other than V5, but linked to it in the normal brain, are capable of mediating the relatively coarse and meagre visual motion capacity possessed by this patient and that area V3 is among them.

Kinetic art and the strategy of minimalist physiological stimulation of cortex

We shall show below that, in its development, kinetic art underemphasized or even eschewed form and colour in its efforts to promote motion. In fact, in developing kinetic art, artists initially used visual stimuli that were not especially well suited to activate areas V3 and V5 selectively, since they were composite drawings relying heavily on form and colour to *suggest* motion. Good examples are Boccioni's *The City Rises* (Fig. 18) and Duchamp's *Nu descendant l'escalier* (Fig. 11), compositions in which movement is inferred, not seen. By deemphasizing colour, kinetic artists then tailored their art to stimulate optimally the two M-dominated areas, V3 and V5, as in the *Méta Malevichs* and especially in the *Métamatiques* of Tinguely (Fig. 22). Finally, by de-emphasizing form as well, they reduced it even more to an optimal stimulation of V5 and its satellite areas, as in Calder's mobiles (Fig. 23). It is interesting to consider the physiological counterpart of this. The restriction in the use of colours would not affect the cells of V5 or V3 since, being indifferent to the colour of the stimulus, they would respond equally well whatever the colour. Thus the restriction in colour would probably have the effect of minimizing the stimulation of areas such as V4 in which colour is emphasized (Zeki, 1973; Zeki *et al.*, 1991) while the presence of motion would maximize the stimulation of area V5 and the presence of oriented lines in motion, whatever their colour, would maximize the stimulation of area V3. Using simple oriented lines in motion and therefore targeting V3, or various stimuli in motion and therefore targeting V5, means two things in physiological terms: stimulating the cells of these areas

optimally and stimulating the cells of other areas minimally. There may, however, be additional attentional factors which might 'modulate' the activity of these areas. For example, a central attentional mechanism might 'switch on' area V5 and 'switch off' area V4 when the spectator is viewing a mobile by Calder, where motion is emphasized, while the attentional mechanism might act in the reverse direction if colour is emphasized. Attention can modulate the activity of cells in area V4 (Moran and Desimone, 1985) and recent evidence has shown that this is also true for cells in area V5 and its satellites (Recanzone *et al.*, 1993).

The relationship between V1 and V5, kinetic art and the physiology of seeing and understanding

Figure 5 shows that human V5 is situated on the lateral side of the brain, fairly ventrally in the occipital lobe. Its position bears a more or less constant relationship to sulci and gyri in the occipital lobe, even if the position of these sulci themselves is variable (Watson *et al.*, 1993). There are two interesting features about the anatomical location of area V5 in the human brain. The first is its relationship to regions of the cortex which are relatively mature at birth and the second the light that it sheds on the general theory of the cortical processes involved in seeing and understanding the visual world.

It was Paul Flechsig who pioneered the myelogenetic study of the cerebral cortex. He found that certain regions of the cortex, which he called primordial, occupy only a small percentage of the total cortical surface, are relatively mature at birth, judged by the pattern of myelination in them, while other and larger regions, which he called associational, matured at various stages after birth (Flechsig, 1901). Chief among the former is the primary visual cortex, area V1. Surrounding V1 is cortex which would be considered to be associational using Flechsig's criteria and, because it surrounds V1, came to be known as 'visual association' cortex. Although V5 falls within the 'visual association' cortex, a comparison of its position, derived from PET studies, to the myelogenetic maps of the human brain prepared by Flechsig shows that the position of area V5 coincides almost precisely with another field, *Feld 16*, which Flechsig found to be mature at birth, though not quite as mature as the cortex of area V1 (Flechsig, 1920; Watson *et al.*, 1993) (Fig. 6). The early maturity of the cortex of V5 probably indicates its importance in early vision. Is it any wonder that babies should find mobiles, a central feature of kinetic art, so attractive? In fact, motion is one of the most primordial of all visual percepts; even animals with more primitive visual systems have a well-developed system for detecting visual motion.

The second point of interest about the position of human area V5 relates to the fact that it falls within visual 'association' cortex. Implicit in that terminology was a view of the cortical processes involved in vision which was greatly compromised by the discovery of multiple visual areas, their specializations and in particular the functional organization of area V5 itself. That view, prevalent until the early 1970s and adhered to by

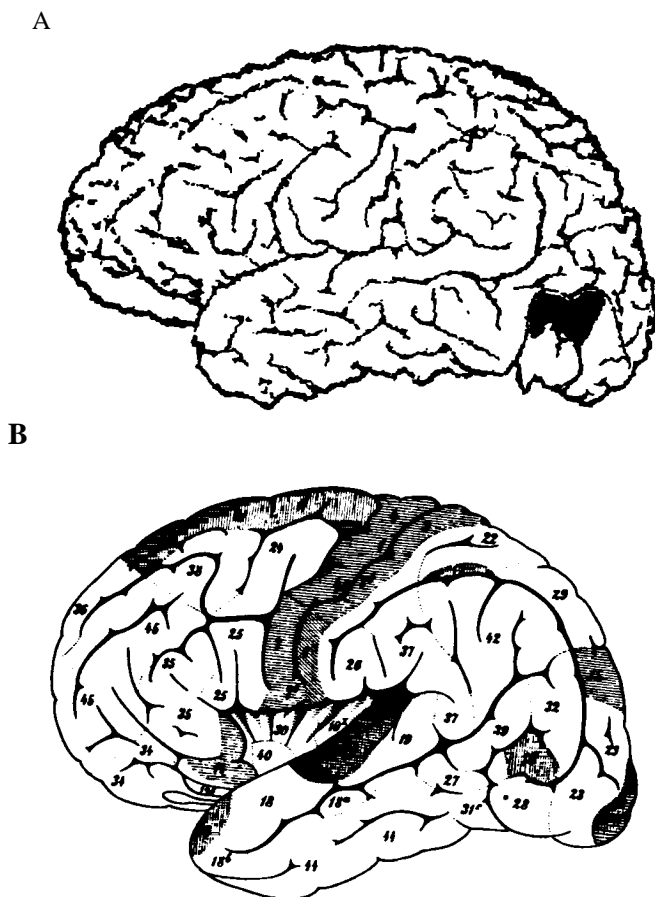


Fig. 6 A comparison of the position of human area V5, as revealed in studies using the PET technique combined to MRI images (*above*) with the position of Flechsig's *Feld 16*, one of the areas which he found to be myelinated at birth. (From Watson JDG *et al.*, *Cerebral Cortex* 1993; 3: 79–94.)

scientists and artists alike divided seeing from understanding and vested the first in the primary visual cortex, V1 and the second in visual association cortex (*see* Zeki, 1993). The first process was thought to involve an image of the visual world, in all its colours, forms and movements, being 'impressed' upon the retina, and then transmitted to be received and passively analysed by a specific part of the brain, the primary visual cortex, a process that led to 'seeing'. The brain area concerned, area V1, was consequently called the 'cortical retina' (Henschen, 1893). Neurologists saw evidence for this supposition in the fact that a lesion in the 'cortical retina' leads to a total blindness, the extent and position of which is in exact relationship to the extent and the position of the damage to area V1. Hence, just as an image of the world cannot be 'impressed' upon a damaged photographic plate, so such an image could not be 'impressed' upon a damaged part of the cortical photographic plate, or the 'cortical retina'. The process of associating the received visual 'impressions' with previous images of a similar kind, leading to the 'understanding' of what was seen, was thought to be the function of a separate cortical area, the visual 'association' cortex, which later also came to be known as the 'visuo-

psychic' cortex. Lesions in it led to the phenomenon which came to be called mind blindness (*Seelenblindheit*) at first and visual agnosia later, following the term introduced by Sigmund Freud. In this condition, patients were thought to be able to see but not to comprehend what was seen, because the necessary 'associative' mechanisms for comparing the received visual 'impressions' with previous 'impressions' were compromised (*see* Zeki, 1993).

The origins of this dualistic doctrine of vision are not easy to trace though the doctrine itself bears a certain resemblance to Kant's belief in the two faculties of sensing and understanding, the former being a passive and the latter an active process. But it was not philosophical speculation that drove neurologists to espouse such a doctrine. There were far more solid reasons, or so it seemed. Chief among these, in addition to the consequences of the lesions in the two areas, was the organization of the connections between retina and cortex as then known, the retina projecting directly (via the lateral geniculate nucleus) to area V1 only and the visual 'association' cortex receiving its visual input from area V1, rather than directly from the retina. It therefore made sense to suppose that V1 alone is the 'cortical retina', the cortex with which one 'sees'. Moreover, the projection from the retina to V1 is very orderly, with adjacent retinal points connecting to adjacent cortical points, thus re-mapping the retina in V1 with a high degree of precision, a necessary step in the faithful transmission of the retinal impression to the 'cortical retina'. Flechsig (1905) thus thought that area V1 was 'the entering place of the visual radiation into the organ of psyche'. It made sense to suppose that the cortex which was responsible for seeing should be mature at birth while that responsible for associating present with past visual impressions should mature in tandem with visual experiences acquired. In brief, all these different facts fed and reinforced each other in support of this dualistic and, in our view, erroneous doctrine of how the brain is organized to see (*see* Zeki, 1993).

A new concept of how the visual cortex is organized and of the cerebral processes involved in vision came with the demonstration that the visual 'association' cortex, which surrounds V1 and which was considered to constitute a single cortical area, in fact consists of multiple visual areas (*see* Zeki, 1978a; Allman, 1987, for reviews). These areas receive their signals from area V1 and are heavily interconnected with it (*see above*). At the very least, this showed that vision is a much more complex process than the one which the dualistic doctrine of the early neurologists had suggested. The turning-point came with the discovery that one of the visual areas (V5), lying in the cortical belt surrounding area V1, is actually specialized for visual motion (Zeki, 1974b). This discovery was complemented by another one, which showed that the great majority of cells in another visual area, V4, lying separately in the same belt of cortex surrounding area V1, is specialized for colour (Zeki, 1973, 1983a,b). Thus was born the concept of functional specialization in the visual cortex. And it is this very specialization that allows artists, on the one hand, to develop an art form which exploits to the maximum the potential of one of these distinct specializations, visual motion, while

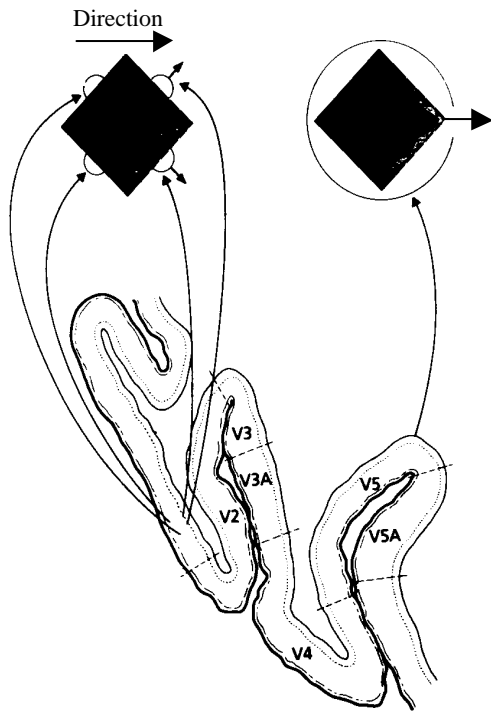


Fig. 7 Component and coherent motion. The orientation plus direction selective cells of V1 (left) have small receptive fields compared with the direction selective cells of area V5. Consequently, if a diamond-shaped object is moving to the right, different cells of V1 may signal that the object is moving in different directions, depending upon the part of the object which falls on the receptive field of the V1 cell. By contrast, the cell in V5 is able to signal the true, overall, direction of motion of the object. (From Zeki SM. *Vision of the brain*. Drawn from the work of Movshon JA *et al.*, 1985.)

minimizing the contribution of other specializations. And it is this same specialization which, on the other hand, enables us to write of the neurology of kinetic art in relation to the distinct visual areas that are specialized for visual motion without at the same time having to consider the relationship of all visual art to brain activity—a much more difficult task. Finally, it is this specialization, and the anatomical relationship of the specialized visual areas to areas V1 and V2 from which they receive their predominant visual input that leads us to the supposition that the process of seeing cannot be so easily separated from the process of understanding what is seen. It would be wrong to suppose, for example, that an akinetopsic patient is able to ‘see’ but not to ‘understand’ motion. The truth rather is that the patient is neither able to see nor to understand certain kinds of motion. The only motion that such a patient is both able to see and to understand is that mediated through the intact area V1 and other prestriate areas, such as V3, which have not been damaged by the lesion. It is these visual areas which presumably contribute explicitly (i.e. without further processing) to such conscious visual motion capacities as this patient has.

The interaction of areas V1 and V5 in visual perception and kinetic art

A consideration of the anatomical connections between V1 and V5 and the physiology of the two areas in regard to kinetic art suggests at once (without recourse to the more detailed anatomical connections between V5 and other areas, which we omit for the sake of simplicity) how interdependent V1 and V5 are anatomically and therefore probably also physiologically. There is an ambiguity in what the directionally selective cells of V1 and V5 signal. The ambiguity with the former cells rests on the fact that they are not necessarily able to signal the coherent motion of a stimulus travelling over a relatively large part of the field of view, even if the stimulus is moving in the cells’ preferred direction. There is, in other words, a lack of precision with which these motion selective cells of V1 are able to analyse motion since, responding to only very small parts of the field of view, they can only analyse motion over small expanses of the visual field (Fig. 7). This imposes a severe problem, since an object moving, say, to the right, may have components that move in different directions (not just to the right). Thus the direction-selective cells of V1, because they are also form (orientation) selective, may register that the object which is moving to the right is in fact moving in all manner of directions (Movshon *et al.*, 1985). When viewing Calder’s mobiles, for example, the different edges of a segment of the mobile moving to the right may excite a number of different cells in V1, each of which signals a different direction of motion. By contrast, a cell in V5, with its larger receptive field, would be able to signal the true direction of motion of the entire segment since the chances of the entire segment, or large parts of it, falling within its receptive field are that much greater. This imprecise way in which V1 analyses the motion of a multifaceted object is therefore possibly rectified by the cells of V5 which ‘look’ at coherent motion, since they can see motion over a larger part of the field of view and can therefore register the true direction of motion of the stimulus, irrespective of the direction in which the particular forms (component orientations) constituting the object, move over small parts of the field of view (Fig. 7). The kind of signalling that the orientation plus direction selective cells of area V1 and the directionally selective cells of area V5 are capable of therefore imposes a certain conflict between the two visual areas (for a review, *see* Zeki, 1993). The cells of V1 may register that an object which is moving to the right is actually moving in all directions. To resolve this conflict, it would be an advantage if the cells of V5 (which register that the object is actually moving to the right) could communicate to the cells of V1 the results of their activity, a process that demands that V5 sends an anatomical output back to V1.

There is another ambiguity, this time in what the cells of V5 signal, which may also demand that V5 inform V1 of the results of its activity. The enlargement of receptive fields in V5 and V3 creates problems because the cells of the latter areas may now lose the ability to pinpoint the precise location of the moving stimuli in the visual field. But the visual system is able

to pinpoint the geographic location of even a small dot in motion very precisely within the field of view. One possibility is that the cells of area V5 or V3 would be able to code for the exact position if a small retinal region is common to the receptive fields of several cells (McIlwain, 1986), i.e. if several cells' receptive fields have a small overlap. How this is achieved physiologically is anyone's guess. Another possibility is that the signals from V5 or V3 must be referred to an area with a highly precise topographic map but, again, the underlying physiological mechanisms are not known. Of all the visual areas, it is V1 which possesses the topographically most precise map. V5 is therefore better able to give the correct interpretation of the motion in the real world and V1 the correct position in visual space. Thus the simultaneous activity of both V1 and V5, and the two-way commerce between them, might be necessary for both seeing and understanding the visual world in motion, and this must apply in kinetic art no less than in common visual perception.

We do not pretend that the two processes of seeing and understanding are inseparable. Everyone knows that there are occasions when one 'sees' things which one does not comprehend. On the other hand, a little explanation allows them to 'see' a great deal more than they had seen before. Thus, while the two processes are not inseparable, the dividing line between the two, physiologically speaking, is hazy, and the two processes are not nearly as separate as earlier neurologists had imagined.

Although the physiology of the reciprocal interaction between areas such as V5 and V3 and the areas which feed them (V1 and V2) are not clear, much more is known about the anatomy which must be at the basis of this commerce. It would help matters considerably, for example, if V1 and V5 were reciprocally connected so that, just as V1 informs V5 of the results of its operation, so V5, in return, informs V1 of the results of its operation. The same applies to V3. It is not surprising to find therefore that both areas reciprocate the input they receive from layer 4B with a return input to it. The nature of these return connections is most interesting. Unlike the forward connections from V1 to these two specialized areas, which comes from segregated groups of cells within layer 4B of V1 (Lund *et al.*, 1975; Shipp and Zeki, 1989a), the return connections from either area to layer 4B are diffuse and encompass the territory of all cells (Shipp and Zeki, 1989a). Thus, the return input from area V5 to layer 4B of V1 is potentially able to (i) influence the cells of layer 4B which project to area V5 and hence to 'modulate' their activity; (ii) influence the cells of area V1 which project to V3, and which are concerned with form; (iii) resolve any conflict in the responses of cells in area V1 and V3 or V5 (Zeki and Shipp, 1988) (*see below*). Equally, through its diffuse back-projection to layer 4B, V3 is capable of the same kind of diffuse influence. Both V3 and V5 also receive input from a specific compartment of area V2 (the thick stripes), which itself receives input from layer 4B (Shipp and Zeki, 1985, 1989b; Livingstone and Hubel, 1987a). But the return input from V3 and V5 to V2 is not restricted to the territory of the thick stripes; instead, it invades the territory of the other stripes as well, thus enabling the two areas to influence cells in the other stripes

which deal with other attributes of vision, specifically form and colour (Shipp and Zeki, 1989b). Finally, V3 and V5 are connected directly with one another.

It follows that V5 can influence V3 directly or through areas V1 and V2. It follows, too, that through these intimate and extensive links, the simultaneous activity of all three or four areas may be important in kinetic art, especially when both form and movement are important ingredients, as they commonly are.

The consequences of bypassing V1 and channelling kinetic signals directly into V5

However important the anatomical relationship between V5 and V1 may be, recent evidence suggests that V5 can nevertheless mediate a conscious perception of visual motion if activated directly through a route which does not go through V1. Lesions in area V1 generally lead to total blindness and hence an inability to see visual motion. Lesions in V5, however, lead to akinetopsia or a specific inability to see objects when in motion (Zihl *et al.*, 1983, 1991). One may conclude that this pathology reflects the fact that all signals go to V1 first and that signals related to motion are subsequently selectively channelled to V5, lesions in which consequently lead to a milder defect, in one submodality of vision alone. But there are other routes from the retina to V5 and they bypass V1. One consists of the direct projection from the lateral geniculate nucleus to the prestriate cortex (Benevento and Yoshida, 1981; Fries, 1981; Yukie and Iwai, 1981). Another possible route is that linking the pulvinar nucleus of the thalamus, which receives an input from a midbrain visual centre, the superior colliculus, to the prestriate cortex (Standage and Benevento, 1983). It seems likely that these routes are able to nourish V5 sufficiently for it not to be entirely dependent upon area V1 for its specificity, namely directional selectivity to motion. It has been shown, for example, that the characteristics of monkey V5 are not abolished when it is deprived of its input from V1 (Rodman *et al.*, 1989; Girard *et al.*, 1992). Instead, the directional selectivity that is so prominent a feature of V5 remains, although cells become much more broadly tuned and lose the crispness and selectivities that are evident in a V5 receiving a direct input from V1. Moreover, one can infer from the results of Beckers and Hömberg (1992) that visual signals may reach V5 before reaching V1. This anatomy and physiology makes it interesting to ask whether the direct subcortical input to V5 is sufficiently potent to mediate a direct, conscious experience of visual motion, one which is both seen and understood by the subject, a topic which we have addressed in recent PET experiments, using a patient with residual motion vision (Barbur *et al.*, 1993).

Subjects with residual vision are ones who, following a lesion affecting area V1, become blind but who can, in spite of this, nevertheless discriminate certain kinds of visual stimuli, in particular visual motion (Blythe *et al.*, 1987). Their visual experience, in other words, is grossly abnormal whereas their ability to discriminate the direction of motion of a visual stimulus

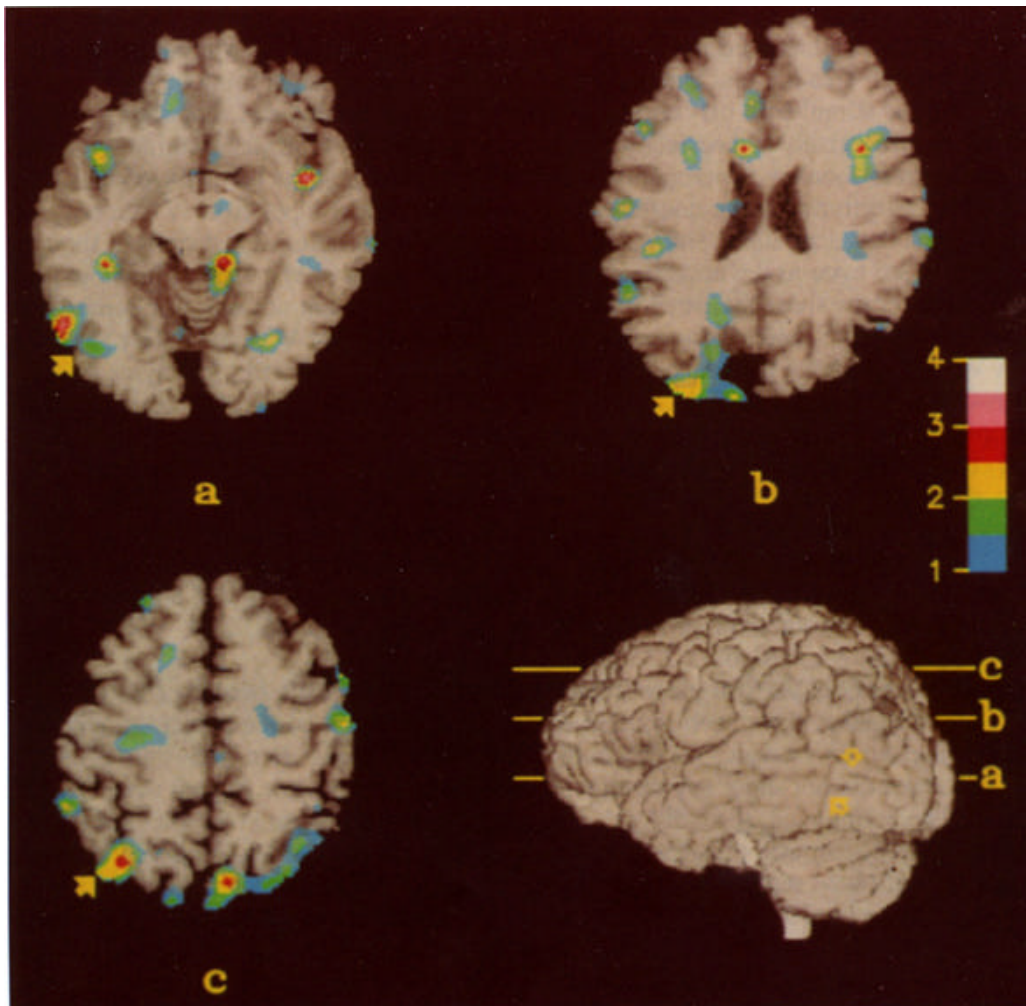


Fig. 8 The activity in area V5 in a subject with residual motion vision following lesions in area V1 of one hemisphere. The rCBF was measured, and significant changes detected, when the subject was exposed to, and asked to discriminate, the direction of motion of bars presented to his blind hemifield. The activity in area V5 is indicated by an arrow in a, while activity in V3 is shown in a. c shows the activity in parietal cortex. The pattern of activity in the prestriate cortex shows that visual motion signals can reach area V5 directly, without going through V1 first and that such activity in V5 and other visual areas of the prestriate cortex is sufficient to sustain the conscious perception of visual motion. (From Barbur *J et al.*, *Brain* 1994; 116: 1293—302).

is good. Our patient was completely blind in one-half of his field of view (hemianopic) because of a seemingly total lesion affecting area V1 of one side. Because area V5 was intact, it was possible to study the kind of visual motion experience that such a patient would have when signals reach V5 without going through V1 first. The change in rCBF was measured in this patient while he discriminated the direction of motion of bars and compared with the change in rCBF when the patient viewed static bars. In spite of his apparent blindness, he reported that the stimulus presented to his blind visual field was 'in motion' and reported verbally, to 100% accuracy, the direction in which the bar was moving, provided the stimulus was of very high contrast. The PET results showed that, under these conditions, the significant change in rCBF occurred in area V5 and in putative area V3, implying that visual signals do indeed reach these areas, without passing through area V1 first, since V1

was absent (Fig. 8). It thus seems that the arrival of kinetic signals in V5 and in V3 is sufficient to lead to the perception of visual motion and that the activity there has access to conscious awareness, in so far as the subject was aware of the nature of the visual stimulation and verbalized this experience, even if it was a grossly abnormal visual experience. It also demonstrates that these areas can contribute explicitly to conscious visual perception, without the aid of V1.

The above review lays the minimum necessary ground for any neurologically plausible discussion of the brain's experience of kinetic art: a specialized input to area V3 and, above all, area V5; the reciprocal connections between the two areas as well as between them and areas V1 and V2, which feed them; the physiological properties of areas V3 and V5 which make them especially well suited for detecting dynamic forms and coherent motion, independently of colour. Whether the

stimulation of these areas alone can lead to the aesthetic component is far from being known. Both V3 and V5 have further cortical connections and these may well play a critical role in the aesthetic dimension. What is certain is that without these areas, the subject cannot see, let alone appreciate, kinetic art.

Part II: The development of an art form that highlights visual motion

Origins and development of kinetic art

It took a long time, and some experimentation, to realize that visual motion, not form or colour and not the combination of all three, is the effective stimulus for V5. It is as if the area emphasizes visual motion at the expense of both colour and form. Equally we now realize that it is oriented lines, particularly when set in motion, not colour or a combination of colour and oriented lines, that best activates the cells of area V3, as if moving straight lines are emphasized at the expense of colour. It is a striking fact that there is an evolution in kinetic art, reviewed in the next section, which also tries to free movement from both colour and form, as if attempting to stimulate maximally areas V3 and V5, in combination first and then perhaps area V5 alone.

The origins of kinetic art are relatively easy to establish. It started as a dissatisfaction, ostensibly due to political and social factors, with an art which seemed to exclude the kinetic element, or what Naum Gabo called the fourth dimension (*see* Rickey, 1963), in works of visual art. The first steps taken to remedy this omission were timid and tentative but, throughout, the tendency has been to emphasize motion at the expense of both form and colour. We distinguish three interdigitating stages in the genesis and development of modern kinetic art:

A first stage in which the importance of having actual movement was explicitly acknowledged in the manifestos and writings of artists and timid steps, not always brought to completion, taken to include motion in works of art.

A second stage in which objects were actually set in motion, so that the movement of the object itself became part of the work of art. Many of the artistic creations falling into this stage would have been powerful stimuli, not only for area V5 which is specialized for visual motion, but also for area V3, whose cells respond especially well to oriented lines and edges in motion (dynamic form).

A third stage in which an effort was made to detach movement as far as possible from both the form and the colour, i.e. to approximate the stimulus (the work of art) as nearly as possible to the physiology of area V5.

Timid flirtation with movement and its static representation

The first stage is perhaps best exemplified by the notes of Marcel Duchamp, the 'Frenchman who engages himself in dissecting sensations and sentiments' (Estienne, 1954), for the creation of works of art in which actual movement was of critical importance. Duchamp started writing the notes quoted below in 1914, a period during which he must have

had motion very much on his mind, though he did not exploit it explicitly, perhaps because he did not know how to do so or had not yet settled on the best way of doing so. Perhaps, as Rickey believes, 'Duchamp showed, by deferring his work with movement for years and confining it to optical phenomena, that his concern therein was dadaist and superficial' (Rickey, 1963). At any rate, by 1911 he had finished *Dulcinea* (Fig. 9) which is strongly suggestive of movement in static terms. The same year saw several other canvasses in which motion plays a central part, though in each it is represented statically. For example, in the *Coffee Mill* (Fig. 10), the handle of the mill is depicted in several positions, to convey an impression of motion, and an arrow marks the direction of motion. The following year, 1912, also saw a number of paintings in which motion played an important role, though none is kinetically innovative in that none did anything more than convey the idea of motion statically. Of these, the most famous is *Nu descendant l'escalier II* (Fig. 11), a tableau that '...initiated no new developments in painting, and such interest as it has relates to the artist's misguided effort to introduce motion into an essentially static medium' (Rosenberg, 1983). Duchamp's description of it suggests that he had been influenced by movement and had had it on his mind. He explained that the final version of the *Nu* 'was the convergence in my mind of various interests among which the cinema, still in its infancy, and the separation of static positions in the photochronographs of Marey... the anatomical nude does not exist, or at least cannot be seen, since I discarded completely the naturalistic appearance, keeping only the abstract lines of some twenty different static positions in the successive action of descending' (Duchamp, 1912). However, in 1913, he produced his famous *Bicycle Wheel* (Fig. 12), the '*ReadyMade*' which he called a *Mobile* and which is commonly thought to constitute a precursor of kinetic art, although as usually exhibited it is not in motion. Moreover, the *Bicycle Wheel* was only one of many ready-mades which included, among other things, a urinal and other non-moving objects. Duchamp did not see these as aesthetic objects at all, quite the contrary. 'A point which I want very much to establish', he wrote, 'is that the choice of these 'readymades' was never dictated by an aesthetic delectation. This choice was based on a reaction of *visual* indifference with at the same time a total absence of good or bad taste ... in fact a complete anesthesia' since the characteristics of a 'true' ready-made were: 'no beauty, no ugliness, nothing particularly esthetic about it' (Duchamp, 1920) (his emphasis). The *Bicycle Wheel*, therefore, belongs more to the ready-mades and less to kinetic art, certainly less than optical devices such as the *Rotoreliefs* which he designed later. It is therefore hard to imagine that it represents a stage in Duchamp's kinetic development when he broke loose and came close to using movement itself to represent motion. Indeed, Duchamp's record shows that, far from being able to dissect sensations, or at least the kinetic sensation, he actually experienced very great difficulty in doing so, at least in painting. In fact, the kinetic element may not have been his only, or indeed major,



Fig. 9 Marcel Duchamp, *Dulcinea* (Philadelphia Museum of Art: The Louise and Walter Arensberg Collection.)



Fig. 10 Marcel Duchamp, *The Coffee Mill* (By permission of the Tate Gallery, London.)

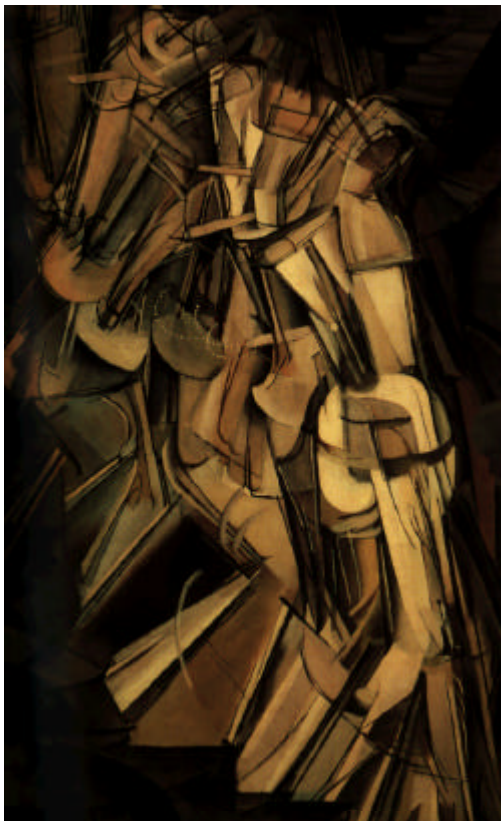


Fig. 11 Marcel Duchamp, *Nu descendant l'escalier, II* (Philadelphia Museum of Art: The Louise and Walter Arensberg Collection.)



Fig. 12 Marcel Duchamp, *Bicycle Wheel* (Philadelphia Museum of Art: Given by the Schwartz Galleria d'Arte.)

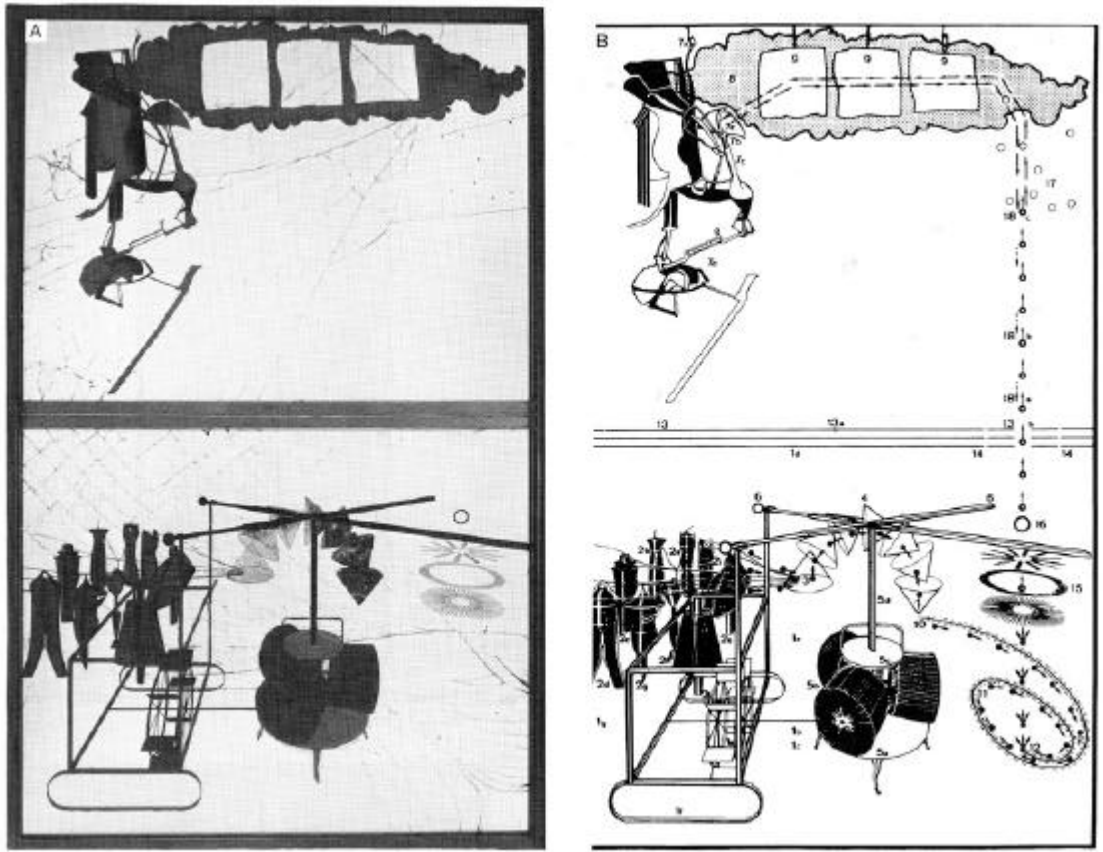


Fig. 13 A, Marcel Duchamp, *La mariée mise en nu par ses re célibataires, même (Le grand)* (19 15–1923). (Philadelphia Museum of Art: Bequest of Katherine S. Dreier.) B, Marcel Duchamp, sketches for *La Mariée*.

concern. Duchamp was especially interested in depicting change (Matta, 1993), and a prime example of this is his *Le Passage de la Vierge à la Mariée* (1912). The following lines, taken from Duchamp's notes for *La Mariée* (Fig. 13) which he wrote in 1914, illustrate our point well:

'This tormented gearing gives birth to the desire-part of the machine This desire-part—then alters its mechanical state—which from steam passes to the state of internal combustion engine.

'The Bride basically is a motor. But before being a motor which transmits her timid-power. -she is this very timid-power--This timid-power is a sort of automobiline, love gasoline, that, distributed to the quite feeble cylinders ... is used for the blossoming of this virgin who has reached the goal of her desire- (Here the desire gears will occupy less space than in the bachelor machine.- They are only the string that binds the bouquet.)

'This blossoming-effect of the electrical stripping should, graphically, end in the clockwork movement (electrical clocks

in railway stations) Gearwheels, cogs, etc (develop expressing indeed the throbbing jerk of the minute hand. 'The motor with quite feeble cylinders is a superficial organ of the bride; it is activated by the love gasoline, a secretion of the bride's sexual glands and by the electric sparks of the stripping. (to show that the bride does not refuse this stripping by the bachelors, even accepts it since she furnishes the love gasoline and goes so far as to help towards complete nudity by developing in a sparkling fashion her intense desire for the orgasm.' (Punctuation as in the original.)

Anyone who, after reading these notes, imagines that what Duchamp had in mind was a tableau in motion could be easily forgiven. In fact, the tableau itself is totally static and its real significance is difficult to appreciate by the first-time viewer, unless he is acquainted with Duchamp's writings on the subject. The final product must be regarded as something of a disappointment from the point of view of kinetic art, though it was perhaps not for Duchamp who had a deep interest in

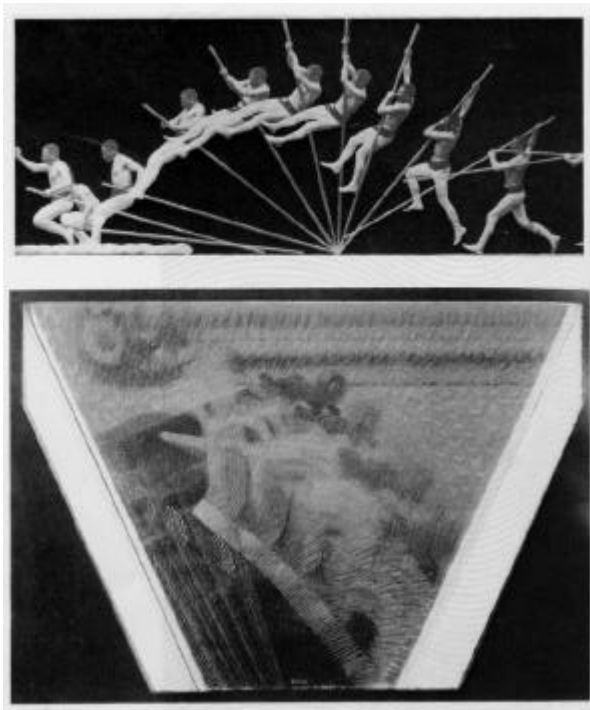


Fig. 14 Top: Etienne-Jules Marey, *Saur en longueur*. (By permission of the Musée Marey, Beaune.) Bottom: Giacomo Balla, *The violinist's hand*. (By permission of the Eric Estoric Family.)

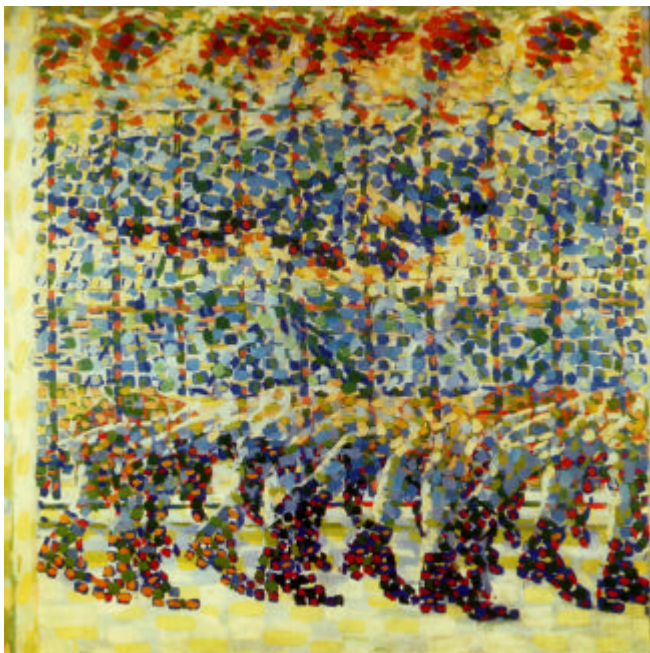


Fig. 15 Giacomo Balla, *Bambino che corre sul balcone*. (By permission of the Civica Galleria d'Arte Moderna, Milan.)

sexual mechanics which includes an element of motion, and his intentions may not therefore have been concerned solely with kinetics. It is only later, from the 1920s

onwards, that Duchamp created his *Rotoreliefs* (optical discs), spirals in motion, which are truly kinetic in the sense of being in actual motion. Given the activation of the V5 complex with the illusory rotatory motion (*see below*), it may be surmised that the *Rotoreliefs* would also activate the same area.

It is significant that Duchamp started writing about *La Mariée* in this way from 1914. This was during the period when the idea of movement began to ferment in artists' minds. The gulf between the idea and its implementation in works of art was not easy, however. The latter naturally required some elementary degree of technical mastery, of getting at least parts of the work of art into motion. This is perhaps one reason why actual incorporation into works of art was to take a relatively long time. We thus note that in the *Manifesto of Futurism* of 1909, Marinetti stated emphatically: 'Nous déclarons que la splendeur du monde s'est enrichi d'une beauté nouvelle: la beauté de la vitesse.' But nowhere did Marinetti put this declared splendour into practice. Instead, artists, even those like Marinetti who had exalted movement, continued representing motion in static forms though showing signs of the influence of Jules Etienne Marey's photographic creations, as is evident from comparing such works as Marey's chronophotographic study of human locomotion and Giacomo Balla's *Violin Player* or his *Bambino che corre sul balcone* (Figs 14 and 15). Or, like Ettore Bugatti, they abandoned painting altogether and pursued new, motion-based ideas such as the automobile. The Dadaists, who were influenced by Futurist techniques, also saw in motion the unpredictability that they had yearned for and dreamed about. Francis Picabia designed imaginary machines, such as his *Machine tournez vite* (c. 1916—18) and his *Parade amoureuse* (1917), the latter somewhat reminiscent of Duchamp's *La Mariée* and, like it, related to nihilism and lacking real motion. Until Calder invented his mobiles, the generation of motion depended upon machines and machines did not seem beautiful or desirable works of art to everyone. Duchamp, who had an equivocal attitude to the aesthetic value of some of his artistic creations, told Jack Burnham that he considered machines to be non-artistic (non-art) (Lebovici, 1991). The first stage in the development of kinetic art thus defies a relatively simple physiological analysis at the present time. The compositions that characterize it are too complex and rely maximally on form and colour and minimally, if at all, on actual motion.

Motion from form and activity of the V5 complex

We know nothing at all about how the brain responds to the suggestion of motion, made in static terms. Studies using PET would be awkward to undertake because of the difficulty of isolating from the paintings mentioned above a single factor which suggests motion, and then study the activity of the brain with and without that factor, to see how the suggestion of motion may be mapped or represented in the brain. How would one go about modifying Boccioni's paintings or those of Balla to

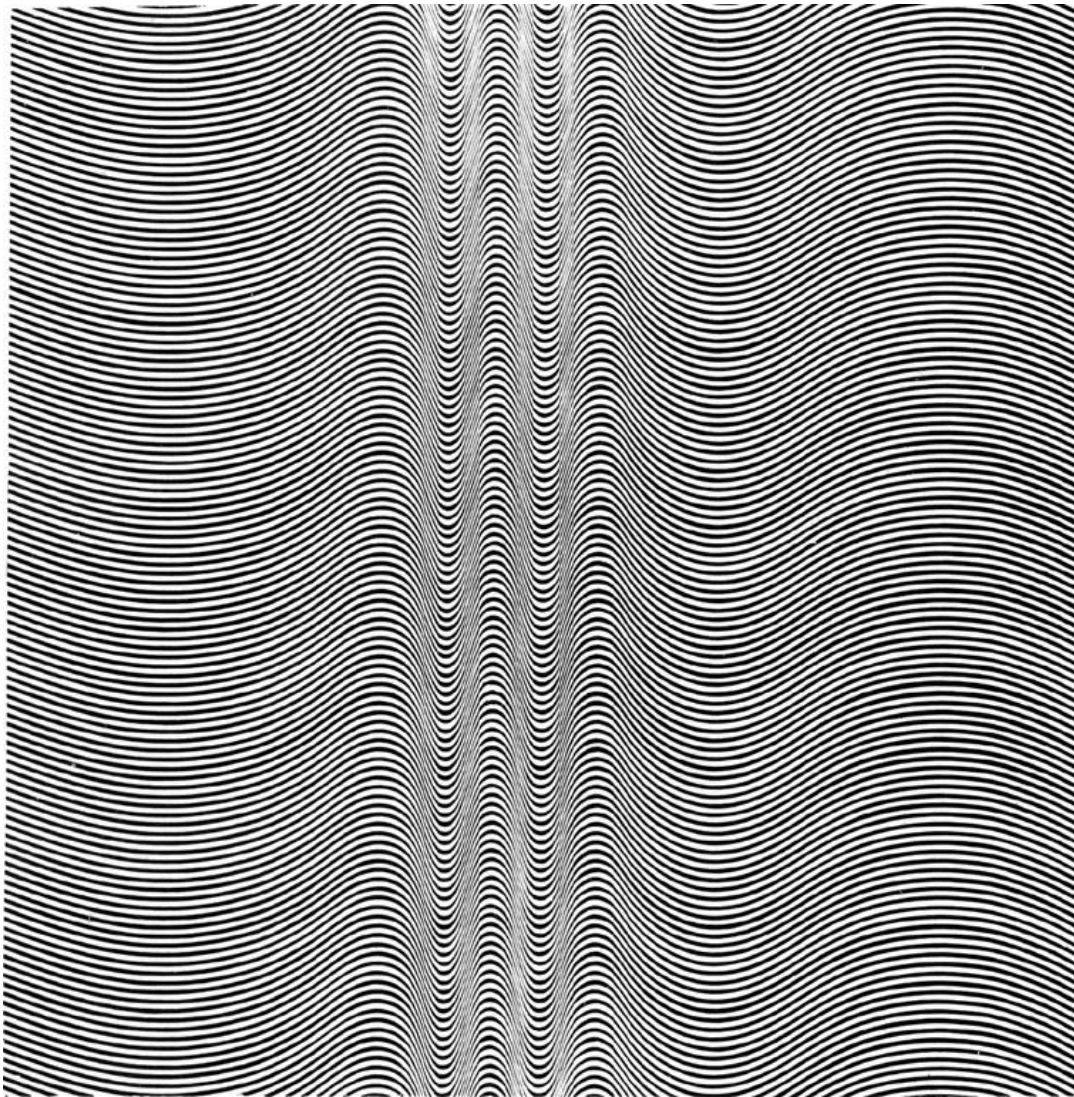


Fig. 16. Bridget Riley, *Current*, 1964, synthetic polymer paint on composition board, 148.1 x 149.3 cm. (The New York Museum of Modern Art, New York.)

extract the suggested motion element? A far easier way is to use another kind of art, i.e. one in which motion is actually perceived though it is not physically there. The latter is of special interest, because we make the argument that it is activity in the visual areas of the brain which are specialized for visual motion perception that induces the perception of motion in certain works of art, in which the motion is entirely illusory and not physically part of, or present in, the visual stimulus. To paraphrase Edwin Land's statement about colour vision, the perceived motion in such works of art 'is always the consequence, never the cause' (Land, 1985). In other words, the pattern in the work of art induces an activity in these areas and that activity in turn invests the static work of art with motion.

This phenomenon of motion from form is a feature of some relatively recent works of art, in particular those of Bridget Riley (Fig. 16). Many observers perceive a movement in these works although there is no physical motion actually there. The phenomenon is nicely demonstrated in *Enigma*, the work of Isia Leviant (Fig. 17A). The striking feature in this figure to most, but not all,

observers is a strong perception of motion in the circles, the motion being relatively rapid, in opposite directions in the different circles, to which it is restricted, and changing directions with sustained viewing. The motion is much reduced, if not abolished, when the spokes are made to intersect the circle, the two versions being adjusted for brightness (Fig. 17B). We wanted to learn whether there would be an enhanced activity in area V5 when humans view *Enigma* and see the motion in the rings; we therefore compared the rCBF in the brains of individuals who viewed the two versions of *Enigma* (Zeki *et al.*, 1993). To check whether the activity would be in area V5 itself, we also looked at the rCBF when the same subjects viewed the moving and static versions of the stimulus originally used to define V5, i.e. we compared the brain activity when the same subjects viewed the stimulus in its moving and stationary modes. The results showed that, when subjects had been viewing the dynamic version of *Enigma*, the significant change in rCBF in the visual cortex was restricted to the region

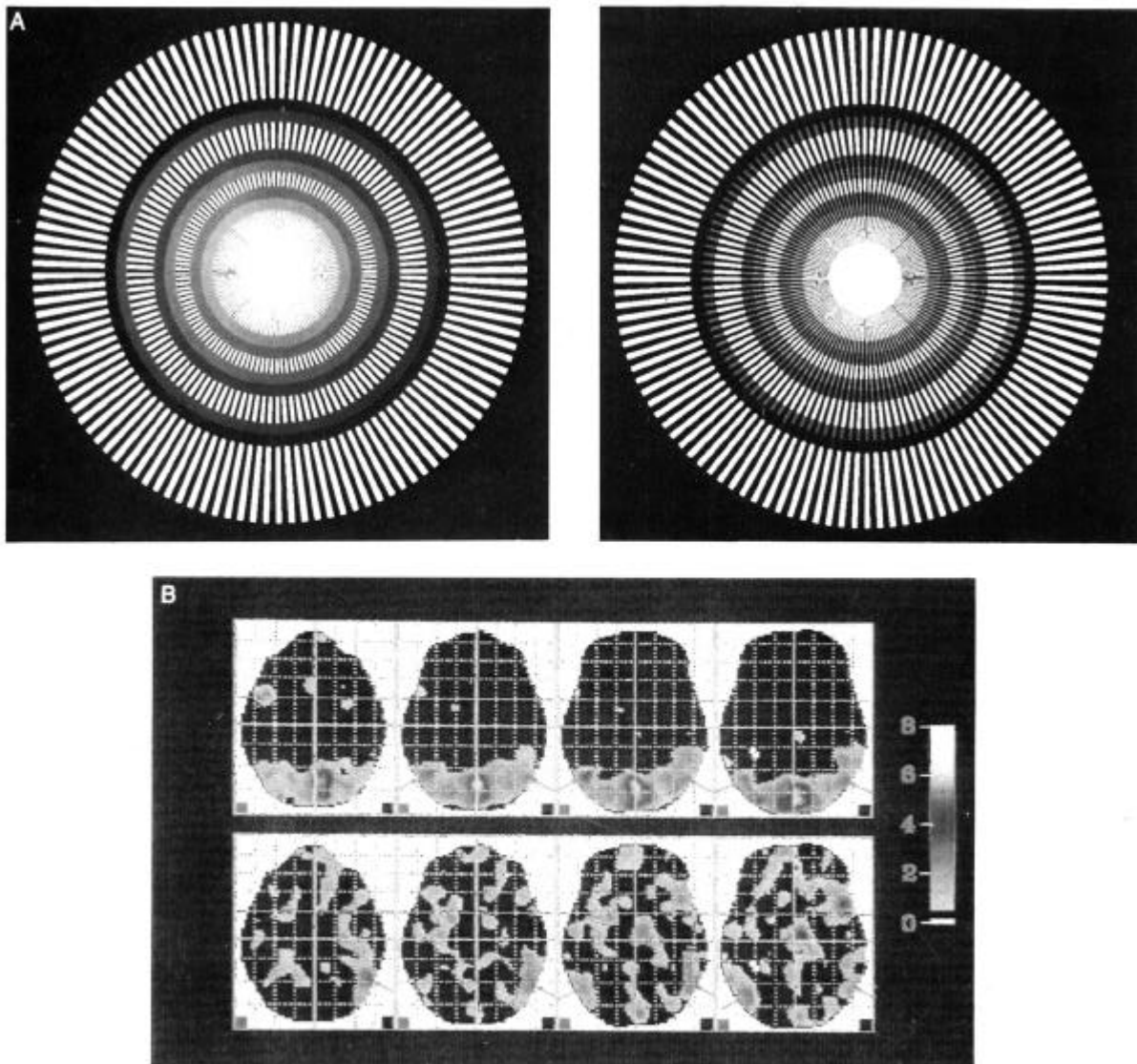


Fig. 17 A, *left*, motion from static form, in a figure (*Enigma*) designed by Isia Leviant (Palais de la Découverte, Paris); *right*, the same figure but with the spokes intersecting the circles, thus reducing the motion component substantially. **B**, the activity in area V5 shown in horizontal slices through the brain. Top row shows the activity in V1 and in V5 (with arrows) when subjects view a visual stimulus which is actually in motion. Bottom row shows activity in the vicinity of V5 and overlapping with it (arrows) when human subjects view motion generated from form (illusory motion) (Results from Zeki *S et al.*, Proc R Soc Lond Biol 1993; 252: 215 —22.)

of area V5. In fact the activity, though overlapping area V5 as defined in the same brains by the use of objective motion, was not restricted or identical to it. Instead, it surrounded V5 both inferiorly and anteriorly (Fig. 17B). This suggests that it was the V5 complex, rather than area V5 alone, which was active during the viewing of *Enigma*. The result gains physiological significance from the fact that there are cells in the satellite areas of V5 which respond specifically to rotatory motion (Tanaka *et al.*, 1989). But more significant in this context is that it is activity within specialized visual cerebral areas, not throughout the visual cortex and not in V1, which is particularly important in inducing the perception of motion in a stimulus in which there is no objective motion. It is as if, in studying the relationship between brain activity and the perception of at least some works of kinetic art, one

should be enquiring not only into what the visual stimulus does to the cerebral cortex but also, and in particular, asking what the cerebral cortex does to the visual stimulus. No-one has recorded from the cells of V5 in a behaving monkey to study the physiological basis of this kind of phenomenon; the nature of the activity which leads to the perception of motion in a static visual stimulus is therefore not known, nor is it known whether V5 would be active when subjects close their eyes and imagine motion or view a picture in which there is a suggestion of motion, for example in Balla's *Violin Player*. But the PET experiments show that an initial physiological study of such phenomena can be narrowed to area V5 and its satellite areas. In fact, it is likely that the perception of motion involves cerebral

areas outside the visual cortex for, in our PET studies with *Enigma*, regions of the cingulate and of the frontal cortex were also active. What the role of the latter areas may be is far from known. The point which we are making here is that one cannot ascribe the motion generated in these static figures to some sort of illusion or deception, or to some sort of trick that the artist is playing on the spectator. Rather, in their experiments with art, artists were unknowingly revealing something about the organization of the visual brain in general and of V5 in particular and, in this specific example, an undefined feature about the activity within the V5 complex which generates motion from static forms and invests their work with motion.

The incorporation of actual movement into works of art

The second stage is almost contemporaneous with the first, or at least interdigitates with it. It has its origins in the manifesto which is somewhat grandly entitled *Ricostruzione Futurista dell'Universo* (Balla and Depero, 1915). This manifesto is explicit in demanding the execution of dynamic sculptures. It casts Balla in the somewhat prophetic role of the one who 'sentì la necessità di costruire... il primo complesso plastico dinamico'. The manifesto uses categories such as 'Dinamico. Moto relativo (cinematografo)+moto assoluto' and 'Trasparentissimo. Per la velocità e per la volatilità del complesso plastico'. Here, then, is the explicit suggestion of the incorporation of motion, including different categories of motion, for example velocity, into the art work. In fact Fortunato Depero actually produced in 1915 a dynamic piece of sculpture entitled *Complessoplastico policromafico e mobile: tre strati di diversa colorazione che si muovono in tre semi diversi*, a work since destroyed. Although emphasizing the element of motion, the new creation relied heavily on colour and thus had still not liberated motion from the other attributes of vision. Physiologically, therefore, it was still heavily dependant upon stimulating those areas of the brain which are concerned with colour, in addition to the areas specialized for visual motion.

The *Realist Manifesto* of Naum Gabo and his brother Antoine Pevsner, published in 1920, was therefore anticipated to some extent, at least as far as motion is concerned, by the *Futurist Manifesto*. Because neither group was privy to the information that we now have about the separate processing of motion information in the brain, we must assume that it was more of an instinctive process, based on their visual perceptions, that led them to their view of the autonomy of motion as a perceptual phenomenon, and thus one that merited an autonomous depiction in art. Riddoch's claim that motion may be a separate visual percept was made in 1917 and thus after the *Futurist Manifesto* had been published. Although Gabo had studied medicine and natural sciences at Munich University, the view that motion is a separate visual process was not known at that time and Riddoch's claim had not been taken seriously by anyone, indeed had been effectively dismissed by Gordon Holmes in 1918 (see Zeki, 1991). There is therefore no reason to suppose that

Gabo or his brother were acquainted with such a view; they make no reference to it or indeed to the organization of the visual brain in their *Realist Manifesto* of 1920. But, if the move to introducing motion was a more or less instinctive process, dictated in substantial part, if not exclusively, by the physiology of area V5 (as we believe), those artists who emphasized motion came to do so through other considerations, also perhaps in part physiological, as well as through more intellectual exercises, the latter being the least interesting to us from a physiological viewpoint. Indeed, Futurism itself took on political allures and motion became a convenient slogan for the political desire for change. 'I'm delighted to learn', wrote Marinetti, 'that the Russian Futurists are all Bolsheviks' (Marinetti, 1920). As if to emphasize the promised rapidity of political and social change. Marinetti recounts that '... Lenin's trains were decorated on the outside with colored dynamic forms very like those of Boccioni, Balla and Russolo'. But motion also became a symbol for the replacement of outmoded attitudes to art, or so some artists supposed. Thus Balla found some inspiration in his contempt for 'bourgeois art' and for the 'powdered attitude to art' which he considered to be prevalent in Rome. He wanted, Umberto Boccioni tells us, to destroy art in order to re-create it, taking an inspiration from his 'scientific sensibility'. What was the end result? Balla 'began to displace from A to B what before had been immobile' (Boccioni, 1988). But the mobility was, for all that, static (Figs 14 and 15). Others, like Boccioni himself, saw movement as a dynamic law inherent in all objects, explaining that 'immobility does not exist; only movement exists, immobility being only an appearance or a relativity' (Boccioni, 1914). In spite of Boccioni's belief in the motion inherent in all objects, and therefore in the fundamental necessity of representing this, his work too uses static devices to suggest motion. An excellent, and perhaps prophetic, example is his *The City Rises* (Fig. 18), a static picture imbued with colour and form but depicting and suggesting motion, and providing perhaps the first step in the final apotheosis of motion in kinetic art, culminating in Jean Tinguely's *Homage to New York*.

Boccioni's view, expressed above, is not startlingly different from that expressed in the *Realist Manifesto* by Naum Gabo and Antoine Pevsner in 1920. Given that both groups emphasized motion (or, more accurately, time in the case of Gabo and Pevsner) or perhaps because of it, one detects an element of hostility, at least from Gabo and Pevsner towards the earlier Futurists. They wrote that 'One had to examine Futurism beneath its appearance to realise that one faced a very ordinary chatterer, a very agile and prevaricating guy, clad in the clatter of worn-out words ... and all the rest of such provincial tags.' The incorporation of motion came in for special venom. They wrote, 'The pompous slogan of Speed was played. ... as a great triumph. We concede the sonority of that slogan ... But ask any Futurist how does he imagine 'speed' and there will emerge a whole arsenal of frenzied automobiles, raffling railway depots, snarled wires, ... does one really need to convince them that all that is not necessary for speed and for its rhythms?'



Fig. 18 Umberto Boccioni, *The City Rises*, 1910, oil on canvas, 199.3x301 cm. (The Museum of Modern Art, New York. Mrs Simon Guggenheim Fund.)

Stripped of its polemical element, the above quotation is not without interest. We see it more as an inarticulate struggle in the minds of Gabo and Pevsner to state what must have been difficult, that movement should be liberated from all that it had been traditionally tied to. Indeed to them time was the essential fourth dimension, to be represented as motion. They wrote, 'We renounce the thousand-year-old delusion in art that held the static rhythms as the only elements of the plastic and pictorial arts. We affirm in these arts a new element, the kinetic rhythms, as the basic forms of our perception of real time' (Gabo and Pevsner, 1920). Gabo was later to become even more explicit in his wish to see movement in art works. He wrote, 'By time I mean movement, rhythm: the actual movement as well as the illusory one which is perceived through the indication of the flow of lines and shapes in the sculpture or in the painting', adding that 'In my opinion, rhythm in a work of art is as important as space and structure and image. I hope the future will develop these ideas much further' (Gabo, 1950).

Dynamic forms derived from Russian Constructivism and the stimulation of area V3

In fact, even in spite of the high sounding titles and the somewhat assertive affirmations, Gabo, like others who

proclaimed the importance of movement, did little in the way of kinetic art, but what he did do is physiologically quite interesting. An early work (Fig. 19) was basically a form which could be set into motion, without exalting motion to the extent that Gabo had implied in his *Manifesto*. It anticipates Hugo Demarco's kinetically more vibrant *Series Relations* of 1988 (Fig. 19). Another work entitled *Kinetic Sculpture* was exhibited in 1922 at the Galerie van Diemen in Berlin, with a catalogue note that read: 'Time as a new element in plastic art' (Rickey, 1963). It was not much later, in 1926, that Laszlo Moholy-Nagy started to design his light machine, *Licht-Raum-Modulator* (Ramsbott, 1960). During the same period, he completed his *Light-prop for an electrical stage* (Fig. 20). In addition to the motion of the component parts, the use in this kinetic sculpture of moving mirrors which reflected moving light in all directions did much to enhance the motion effect produced by the sculpture.

Because the works of Gabo and of Moholy Nagy combined motion and edges, usually straight lines, the above works would all be powerful stimulants for the cells of areas V3 and V5. The prevalence of straight lines of different orientation in these works, influenced at least in part by Russian Constructivism, is not surprising. A great many of the tableaux created by

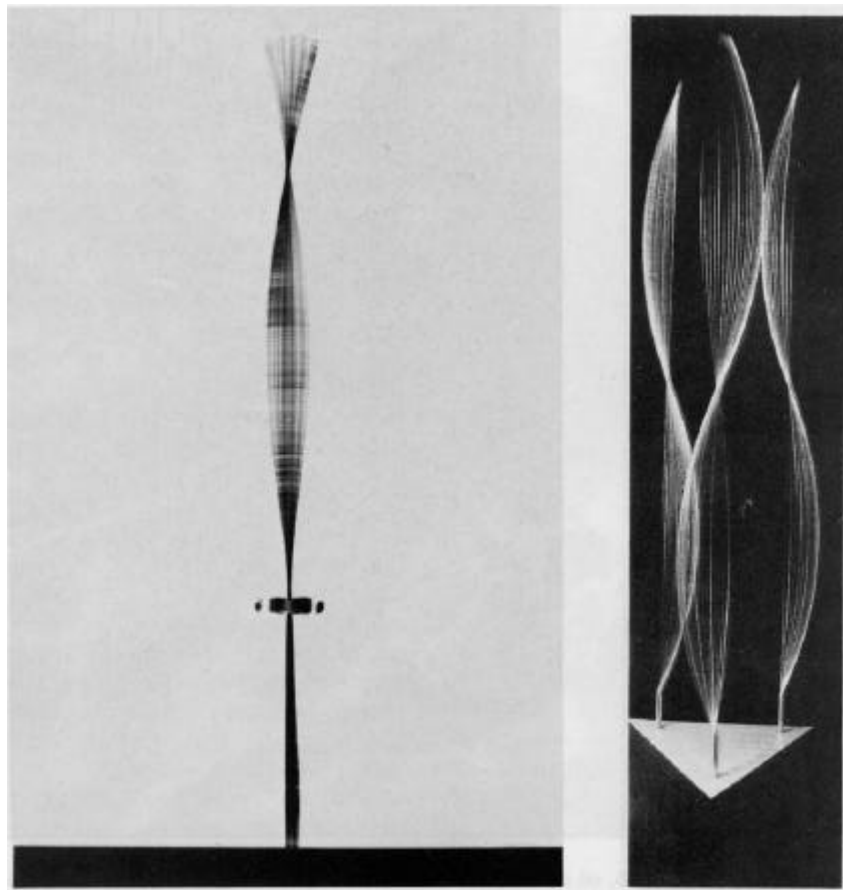


Fig. 19 *Left*, Naum Gabo, *Kinetic Sculpture*. (By permission of the Tate Gallery, London.) *Right*, Hugo Demarco, *Series Relations*. (Artist's private collection.)

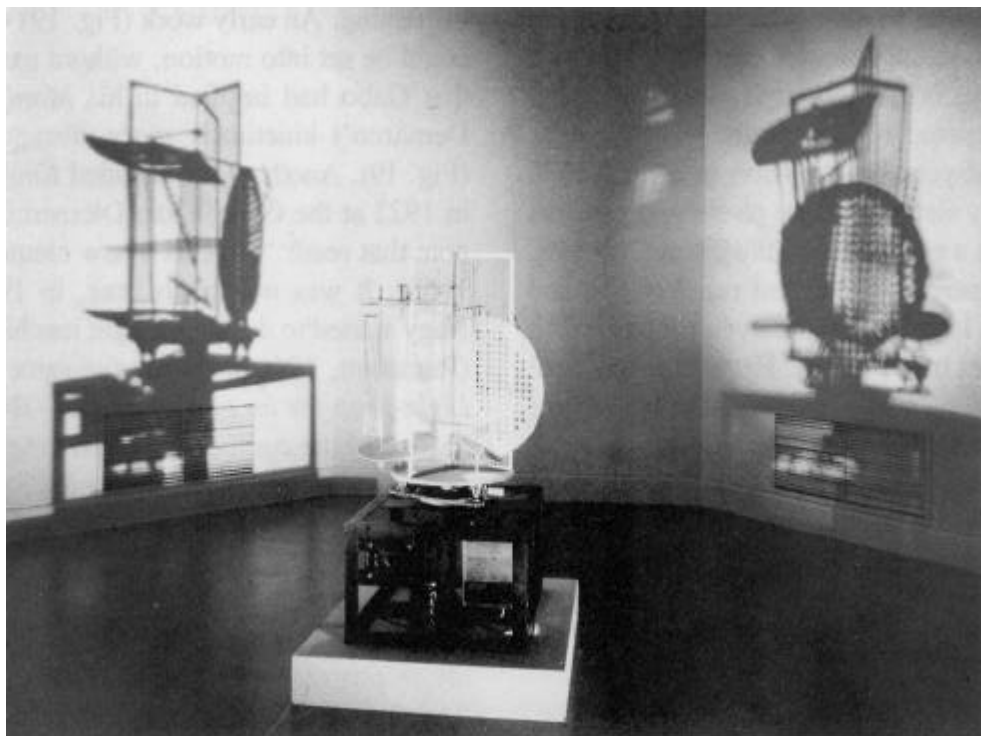


Fig. 20 L. Moholy-Nagy, *Light prop for an electrical stage*. (Van Abbemuseum, Eindhoven, Holland.)

Suprematists and Russian Constructivists were dominated by such straight lines, stimuli which we now know are very potent in activating cells in the visual cortex. The physiological power of these tableaux comes therefore from the use of oriented lines and bars, a dominant feature in many compositions by Suprematist artists such as Kazimir Malevich, Ivan Kliun, Ol'ga Rozanova and Il'ia Chashnik and the Constructivists who were influenced by them (Fig. 21). Over 30 years of physiological research has established beyond any doubt that one of the most powerful ways of activating cells in the visual cortex is to use oriented lines, since many cells there respond to lines of specific orientation (Hubel and Wiesel, 1962). Another reason for the pervasive importance of oriented lines is that orientation selective cells are widely distributed throughout many of the visual areas in the cerebral cortex (Zeki, 1978b). But, within the context of kinetic art, the kind of orientation selective cell that interests us most is the one that derives its input predominantly from the M system and is found in layer 4B of V1 and in area V3, rather than the orientation selective cells that derive their principal input from the P layers of the lateral geniculate nucleus and are located in layers 2 and 3 of area V1 (see Zeki and Shipp, 1988, for a review). The orientation-selective cells of area V3 and of the area adjoining it, V3A (Zeki, 1978c), are not only commonly exquisitely tuned to the orientation of a line but respond even better to the appropriate line if it is set in motion, usually orthogonal to its orientation. Some of the cells of V3 are, in addition, directionally selective, responding to the motion of an appropriately oriented line in one direction but not in the opposite, null, direction. Moreover, just like the cells of area V5, the cells of V3 are indifferent to the colour of the visual stimulus. Hence to activate them optimally, all that is required is to set the protuberances of Pol Bury into their slow motion or set the kind of oriented line that one finds in the tableaux of a Malevich or Rozanova into motion. This is, in fact, precisely what Jean Tinguely—a dominant figure in the world of kinetic art—did in developing this art form. Setting oriented lines into motion, as opposed to having the eye move in scanning static oriented lines (e.g. those in the pictures of the Suprematists and Russian Constructivists), can selectively activate certain groups of cells within area V3. Recently, Galletti and Battaglini (1989) have shown that some cells in area V3, which they refer to as real motion cells, respond only when the oriented line is in motion, not when the eye is moving and the oriented line is held stationary. Thus the shift from the static oriented lines of Malevich to the moving oriented lines of Tinguely's *Méta Malevichs* is more than a shift in artistic emphasis or form. It seemingly entails a shift in the groups of cells activated within V3.

The stimulation of orientation selective cells by Tinguely's Méta Malevichs and Métamatiques

Tinguely was fascinated by motion from an early stage. Nevertheless, his early works such as the *Meta Malevichs* and the *Meta Kandinskys*, which date from the 1950s, are still strongly dominated by form, though of a simple kind.

In these, simple lines and bars of various length, rectangles and squares, and other simple shapes were set in motion by a motor—once again, stimuli that are admirably suited to excite the cells of V3 and V5 and those of layer 4B of V1 from which they derive their input. The motion was not arbitrary, although it was a dominating feature. It was later given an even more commanding presence by the absence of colour and the concentration on black and white geometrical forms, one of the first steps taken to de-emphasize colour in kinetic art, just as V5 and V3 do in their physiology. The forms might return to the same position within hours, or months or even years. The shape at any one moment was unpredictable, but it obviously depended on the past and it specified the future. The only certainty was that of constant change and what it produced at the moment, as in Eliot's poetry, 'Time past and time future ... point to one end, which is always present' (Eliot, 1963). It is difficult to imagine a stimulus better suited to excite the orientation plus direction selective cells of V1 or of V3, especially those which respond selectively to the actual motion of the oriented line (as opposed to motion of the eye over the stimulus), although the *Méta Malevichs* were constructed some years before orientation selective cells were discovered in the cortex (in 1959, by Hubel and Wiesel). Later, in the mid-1960s, Tinguely executed his *Métamécaniques* (Fig. 22), which reached new heights in physiological terms, and contained stimuli which physiologists could hardly have bettered on. The motion of the oriented bars, most of them white against a black background, is once again optimal for stimulating orientation-selective cells in V1 and V3 (Fig. 22). For good measure, they also contain white circular patches against a black background—ideal stimuli for activating the kind of cells (retinal ganglion cells, cells of the lateral geniculate cells or cells in layer 4C of area V1 which receives the predominant input from the lateral geniculate nucleus) which feed the cells of V1. In brief, without ever having realized it, Tinguely seems to have known how best to activate the cells of V1 and V3. But still, these creations were not really optimal for area V5 though, being in motion, they would have excited cells there as well. There was but one step left in the unknowing pursuit of a stimulus that would be tailored for the physiology of area V5. It consisted in the total subordination of form to motion.

The liberation of motion from form and activation of area V5

Whatever grand phrases and high sounding formulas may have been used, those who professed to see motion, or time, as the fourth dimension did not really detach motion and give it an autonomous existence. In their work, motion derived its existence from, or was a part of, automobiles or trains or other gadgets. It was not until the 1930s that Calder introduced, reputedly after visiting Mondrian's studio (Lebovici, 1991), the first of what Duchamp christened 'mobiles' (Fig. 23). This is surprising. The closest Mondrian ever got to motion in his later work is to be found in his static *Boogie Woogies*. Was Calder

the first or did Balla have a better claim, having created a mobile statue of Marinetti as early as 1914? For that matter, Futurists had also experimented with them in a half-hearted



Fig. 21 Kazimir Malevich, *Suprematist Painting* with oriented lines and bars as a central feature. (By permission of the Stedelijk Museum, Amsterdam.)

way. Calder (1959) himself obviously had little doubt. He said, 'When I began to make mobiles, everyone was talking

about movement in painting and in sculpture. In fact, there was precious little of it.' Whatever the priority, there is little doubt that Calder popularized them and planted them in the public mind.

In many ways, the mobile was an ingenious invention. It was not dependant upon any profound knowledge of motors and engineering, although Calder's first mobiles were power driven. Mobiles, in other words, were relatively easy to execute. Motion was the dominant element and, to aid the dominance, Calder decided to limit himself largely to the use of black and white, the two most contrasting colours, as he called them. Red was to him the colour best opposed to these two but all the secondary colours 'confused' the clarity of the mobiles (Calder, 1952). In having circular and rectangular objects of variable size, moving in different directions, and in de-emphasizing colour and form, there is little doubt that Calder had achieved his unknown aim of stimulating optimally the cells of area V5 and, presumably, stimulating minimally the other specialized visual areas. The restriction in the use of colours would not affect the cells of V5, since being indifferent to the colour of the stimulus they would respond equally well whatever the colour. As well, since most are indifferent to the shape of a stimulus, provided it is moving in the appropriate direction, the cells there would not be selective for, and would therefore not signal the presence of, a particular form either.

It is perhaps nevertheless important to emphasize that we do not know what, in physiological terms, amounts to rendering form meaningless. The mobiles of Calder have straight or curved edges, many of the components being in fact triangles or rectangles with curved edges, and the motion of these edges would excite the cells of area V3. To the spectator, there is no definite meaning that can be attached to the form and the sum of the forms does not add up to a more complex form. Rather, the simple rectangular and triangular forms keep changing their position and appearance with the consequence that the overwhelming impression is that of motion. This may be a consequence of the fact that V5 is the more active of the

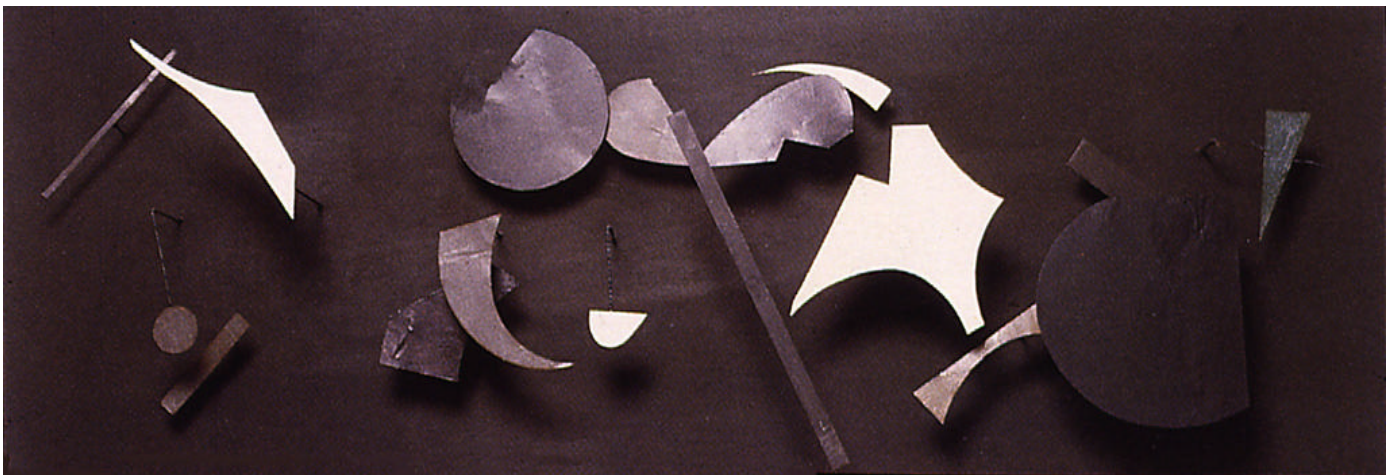


Fig. 22 Jean Tinguely, *Métamecaniques*.



Fig. 23 Alexander Calder, *Mobile with 24 pieces*. (Private collection, France.)

areas or there may be some attentional mechanism that favours V5 and therefore motion, though the latter must be triggered by some feature of the stimulus. What renders the forms meaningless is less certain; we do not wish to imply that V5 itself, in isolation, attaches meaning to the motion component of a stimulus. But the active participation of V5 must be a critical factor, to which must be added other unknown factors such as attention or the physiologically vague 'modulation' and the possible participation of other cortical areas.

Unpredictability in kinetic art and its relationship to visual physiology

From 1934, Calder's mobiles became unpowered; they were usually driven by the wind. 'The important thing', Calder said, 'is that the mobile should catch the wind, whether it be good or bad' (Calder, 1959). And hence a new element was introduced, that of chance and unpredictability. This delighted the poets. Jacques Prévert (1971) wrote a poem about it, describing Calder as 'Horloger du vent' and 'Sculpteur du temps'. Jean-Paul Sartre (1949) described it in lyrical terms. He wrote, 'Ces hésitations, ces reprises, ces tâtonnements, ces maladroites, ces brusques décisions et surtout cette merveilleuse noblesse de cygne font des mobiles de Calder des êtres étranges, à mi-chemin entre la matière et la vie. Tantôt leurs déplacements semblent avoir un but et tantôt ils

semblent avoir perdu leur idée en cours de route et s'égarer en balancements niais. Mon oiseau vole, flotte, nage comme un cygne, comme une frégate, il est un, un seul oiseau et puis, tout d'un coup, il se décompose, il ne reste que des tiges de métal parcourues de vaines petits secousses.' He was not the only one. In a poem entitled *le dernier mot de calder*, Alain Jouffroy (1978) conjured up images of the vast corn fields of the Beauce and of Anjou (the latter possibly a play on the word *joue*),

battue dans le blé de Beauce, ou de l'Anjou,
moissonneuse du vent, moissonneuse du vide, bolide
habité par la langue,
– sommeil en dérive sur ce soleil, la mobilité déjoue le
sérieux des éternels.
personne n'en est la cause, personne n'en est le cas

Other writers have been fascinated by the unpredictability in other examples of kinetic art. Gilbert Lascault (1983) wrote of Pol Bury that 'La mouvement naît d'une alternance du vide et du plein: mouvement qui paraît aléatoire ...' and Pierre Cabanne (1991) found in Pol Bury's jets of water a counterpoint to the irregularity of the slowly moving branches, writing that these '... jets d'eaux qui, outre leur fraîcheur, apportaient un élément de régularité à l'irrégularité des branches d'inox'.

Does the element of chance and irregularity bear any

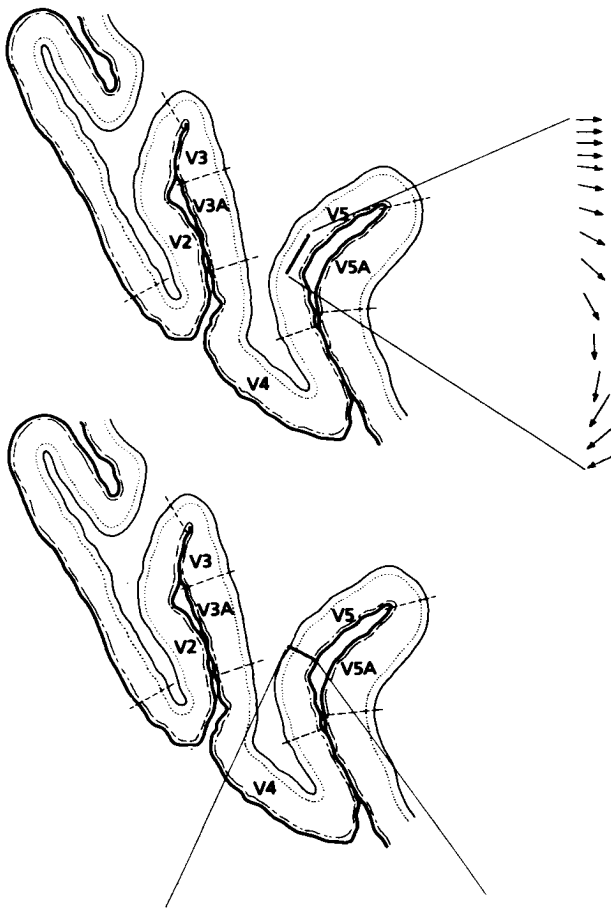


Fig. 24 Regularity of area V5 is illustrated in these reconstructions of penetrations through it. Above is a horizontal penetration through V5 to show that the directional selectivity of successive cells changes in an orderly way. Below is a perpendicular penetration which shows that cells stacked upon one another through the depth of the cortex all tend to prefer the same direction of motion. (From Zeki S. 1993—*A vision of the brain*.)

relationship to the physiology of the areas concerned with visual motion? Using the PET technique, we have compared the activity in two areas, V5 and the area which feeds it, V1, when human subjects view two patterns made of the identical black and white squares, in one of which the squares move chaotically and incoherently while in the other they all move coherently. Our preliminary finding is that the activity in area V5, measured by the increase in rCBF, is very nearly the same whether subjects are viewing the coherent or the incoherent motion. By contrast, when one compares the rCBF, and therefore the activity, in area V1 in response to chaotic and to coherent motion, one finds that the rCBF is much greater with chaotic than with coherent motion (our unpublished results). Assuming there to be a straightforward relationship between the activation of a single visual area and aesthetic experience (an improbable conjecture), area V1 is more likely to be the source of the aesthetic quality of unpredictability than area V5.

The element of chance and unpredictability which so attracted poets and artists is precisely what one does *not* find in the organization of area V5 itself, which, like V3 and all other cortical areas, is highly organized. In V5, cells with common preferences tend to be grouped together and separated from cells with other preferences (Zeki, 1974b; Albright, 1984). Therefore, if one samples the responses of V5 cells in a direction parallel to the cortical surface, charting the directional motion preferences of the successive cells, one finds that the directional preferences of adjacent cells change gradually and systematically, with neighbouring groups of cells responding to neighbouring directions of motion (Fig. 24). On the other hand, if one were to study the directional preferences of cells stacked upon each other in a column extending from cortical surface to the underlying white matter, one would find that nearly all cells respond to the same direction of motion. Equally, if one were to study the functional organization of area V3 or V3A, one would find a remarkable degree of order, with neighbouring cells responding to lines of neighbouring orientation in a particular part of the field of view (Zeki, 1978c). There is, in other words, a high degree of regularity in the functional organization of the area which plays a dominant role in kinetic art. Why the unpredictability in motion (the tongues of fire and the waves of the sea) should have such a powerful effect on most, remains a mystery unanswered by physiology.

The dissociation of motion in kinetic art

The unpredictability inherent in a motion determined by the unpredictable wind was just one element in the forthcoming supremacy of motion. For here, at last, motion seemed to have been detached from form and colour, both of which were to play secondary roles in the mobiles, assuming them to have played a role at all. Jean-Paul Sartre (1949) waxed ever more eloquent about them. He wrote, 'La sculpture suggère le mouvement, la peinture suggère la profondeur ou la lumière. Calder ne suggère rien: il attrape de vrais mouvements vivants et les façonne. Ses mobiles ne signifient rien, ne renvoient à rien qu'à eux mêmes: ils sont, voilà tout; ce sont des absolus.' Motion seemed to be reaching its apotheosis, at least in art. It was to be nearly 40 years before neurobiologists recognized that a specialized visual area of the cerebral cortex signals motion.

Where would movement, kinetic art and the whole art of mobiles proceed now? They did not develop much further in the hands of Calder. His art seems to have become fossilized, with a succession of mobiles differing only according to the direction and intensity of the blowing wind to suggest any difference between them, and indeed resting immobile if stuck in a gallery. In fact, Calder himself executed static sculptures even as late as the 1970s (e.g. his static sculpture *Janey-Waney* at the Louisiana Museum outside Copenhagen, Denmark). His mobiles depended minimally on form, or at least they made form subservient to motion. What was needed was another step, to annihilate form completely, make it utterly insignificant. This was not, and could not be, achieved in the hands of Calder,

the components of whose mobiles moved coherently. Moreover, the mutual interrelationship of substantial parts of each mobile to one another gave the whole work a 'form' or 'structure', however much de-emphasized in favour of motion. The logical sequence would be to develop a work in which structure would be annihilated, thus reducing the whole work to an aggregate of unconnected parts. This was provided by Jean Tinguely.

In 1938, at the age of 13, in the forests that surrounded his parent's home in Basle, Tinguely began to construct idiosyncratic machines that, when turned by the movement of water over their fins, rang bells (Tinguely, 1963). Such imagination signified, early on, an interest in motion that had no utilitarian value. It provided Tinguely with the simple pleasure that he later recalled: 'J'imaginer le promeneur solitaire lui aussi dans la forêt, qui entend d'abord ce concert avant d'entendre les bruits de la forêt' (Tinguely, 1963). Tinguely seems to have lacked that philosophical introspection with which artists commonly invest their sensory discoveries. Instead, his creations show a progression from form-dominated motion, to motion, to motion that devours and destroys form and, finally, to motion that renders form meaningless — all of it achieved in the service of motion as a fascinating percept and with minimal appeal to vague philosophical and metaphysical notions.

The *Méta Malevichs* and the *Métamécaniques* were only a step in what appears, with hindsight, as the domination of movement. Tinguely's work strongly suggests that he continued to experiment to give movement the primacy which he felt it deserved. The moment of his confessed conversion to motion came in observing and studying the work of Georges Mathieu, although it is more likely that Mathieu was no more than the catalyst for the motion-inspired art (we would say the V5-inspired art) which was then germinating within his brain and which he was later to develop. He recounts how he used to watch Mathieu paint, and how it was Mathieu's movements, while painting, that fascinated him. Once finished, the painting ceased to have any fascination for him, for the movement had ceased. It was, in brief, the element of motion that most attracted the visual cortex of Tinguely, though that is not quite the way he explained it. He said, 'I didn't know how to stop a painting . . . I simply couldn't get to the point of saying, "Okay, that's finished" . . . That's basically what made me start to work with movement. Movement was an escape from the petrification, the ending. You could say it allowed me to say "Okay, that's finished"' (Tinguely, 1976). In other words, movement had gained primacy in his thinking. Of Mathieu, he said, 'Cesse d'évoquer le mouvement et le geste. Tu *est* mouvement et le geste. Tu es mouvement et geste' (Calvocoressi, 1982) (our emphasis). Movement, and its cessation, must have made a deep impression on Tinguely. For he began to create works of art which, on another plane, mimicked the kind of effect one imagines Mathieu to have had on him. It is especially instructive to watch (as we have at the Tinguely exhibition in Paris in 1988) the fascination that the works of Tinguely have for children—so long as they are moving. The loss of interest

is complete and sudden once the movement ceases, because the forms undertaking the movement are, in themselves, uninteresting and meaningless. Here was work which did not represent or evoke movement. It *was* movement. One could truly say of it 'C'est le mouvement et le geste'.

But this was to come later. Before he reached that stage, Tinguely passed through a second stage in which movement came to be the centre-piece —the machines that draw, or the *Métamatiqes*. These were machines that, unlike the work of Mathieu, were continually in motion and continually drawing. The drawing acquired its force, not from form, but from the constant and unpredictable motion that created it. No two drawings were ever going to be alike. The *Métamatiqes* were a great success with public and press alike. Eventually, Tinguely designed a new *Métamatiqes* (No. 17) which was driven by a petrol-consuming engine, the smell of the exhaust being nullified by scents and the entire machine making a jangling noise. In reality, Tinguely was more interested in the motion component. And the *Métamatiqes* had not solved his problem because, in them, form was still a significant element, even if it was dominated more or less by motion. Form had to be subdued, made subservient to motion, even annihilated. And thus came *Homage to New York* (1960).

Motion reaches its apotheosis — in art

Homage to New York is a strange piece about which there are many stories. The work, built in the garden of the Museum of Modern Art, New York, was to self-destruct in a celebration of motion, over an half-hour period. Though elegantly planned and contrived, the sculpture did not behave in a particularly deterministic fashion on the evening of the exhibition. That this was so was not at odds with the artist's sympathies, indeed probably much to his secret liking. How little form seemed to count in his latest creation can be gleaned from the fact that Tinguely professed no knowledge when asked about one component of his creation, only admitting later that it must have been a part of the machinery that was to destroy itself. Eventually the machine, in a final exhibition of anarchic motion, caught fire, inadvertently it is said, and, much to the dismay of the assembled spectators, was unceremoniously extinguished by the fire brigade (Kluver, 1960). To observe the sculpture, initially an imposing and static form, and then see this form become subservient to the heightening ferocity of the motion, against the background of the erratic and incoherently moving flames of fire, doused by erratic jets of water, and eventually to be consumed and destroyed by it, must nevertheless have pleased Tinguely, if only secretly — it must have entailed a massive stimulation of area V5. If any one moment can be said to represent the triumph of motion in art, *Homage to New York* must surely be it. Now the circle was complete —Boccioni's *The City Rises*, a complex composition in colour which represents an initial stage in kinetic art, fell apart in an exuberant display of kineticism.

Tinguely's chosen way of destroying form was really to render it meaningless. The vast collections of bric-à-brac that constituted his collections, and which had a long surrealist lineage, acquired an additional interest by virtue of motion. This

is not to say that he did not try other means of supplanting form completely. By emphasizing black and white in his *Métra Malevichs*, he de-emphasized colour. Others, since and before, have tried various means of de-emphasizing form in favour of movement. The declared intention of Jarostav Belik, an engineer artist, is to create machines in which the nature of the work as an object (its form) is minimized while the movement it generates is emphasized, an intention which is almost identical to that of Tinguely except that Belik goes about it in a different way, and is intolerant of unpredictable motion. As well, rather than make the form so complex that it ceases to have any meaning, as with Tinguely's sculptures of the absurd, Belik tries 'to use the simplest geometrical forms possible so that they do not detract attention from the motion' (Belik, 1988). Takis, whom Duchamp described as a '... *laboureur des champs magnetiques*' (Duchamp, 1962) tried another means of keeping the cause of motion forever hidden from view, thus highlighting motion even more. By effecting the motion of objects in magnetic fields he directed the attention of the observer toward that motion, not the force that was causing it. Since the force could not be seen, all that one was left with was the percept of motion. In fact, perhaps the most effective way of dissolving form and heightening movement has been utilized, not by artists, but by scientists.

The annihilation of form through equiluminance

An object, whether stationary or in motion, can be detected because of the luminance or a colour difference between it and its surround, and usually because of both. Hence, if one could arrange things so that the moving object and the background have the identical luminance, the object (whether stationary or moving) would have to be detected by a difference in colour alone. This condition is known as equiluminance. It was first used by Lu and Fender (1972), when they found that the depth seen in Julesz patterns can be abolished if the dots of which the patterns are constructed are made equiluminous. This was followed by the experiments of Ramachandran and Gregory (1978), and others, who showed that the perception of motion itself becomes incoherent, and difficult, if the dots in motion are made equiluminous with the background. One explanation for this may be that the M system, from which V5 derives its principal input, is itself uninterested in colour, indeed is colour-blind. A direct way of testing this would be to stimulate the cells of area V5 with moving stimuli that are equiluminous with the background so that the stimulus can only be detected by a difference in colour between it and the background. When so tested, the capacity of many, though by no means all, cells in V5 to signal motion is compromised (Saito *et al.*, 1989). This suggests that V5 cells are not entirely colour-blind but use colour information to signal motion. This is in keeping with the view that each area of the cerebral cortex will use any kind of visual information, whether derived from the P or the M system, to undertake its function, that of V5 being to signal motion in the field of view (Zeki and Shipp, 1988; Zeki, 1993). However, it is our view that the cells of V5 are not extracting

information about colour, but rather about wavelength, the two being different though often confused (Zeki, 1983b, 1993). The important physiological point here, from a kinetic perspective, is that wavelength itself is rendered subservient to the needs of V5 to signal motion; it is not annihilated in the physiology of V5 but quite simply used to detect motion. Many (e.g. Livingstone and Hubel, 1987b) have seen in this phenomenon the psychophysical and perceptual manifestation of the separation of functions in the visual cortex that physiological and anatomical evidence has provided. But such experiments are very difficult to perform without a high resolution TV monitor, not a favourite art medium, at least for many artists. And it is probably for this very reason that artists have not used equiluminance to highlight motion, turning instead to other devices.

And, because the attempt of denuding motion of both form and colour is almost impossible to achieve without such artificial laboratory experiments, the direction that all kinetic artists have and will take is not to extract pure motion, but to harness the other attributes of the visual scene in the service of motion. Indeed, if there has been a sound physiological basis for artists to try to isolate motion, and thus tailor their art to the physiology of V5, there is also every reason to reintegrate motion with other attributes of the visual scene. This is because the visual cortex, to achieve the greatest possible certainty in categorizing objects according to certain invariant features, in an ever-changing and uncertain visual world (Zeki, 1993), will use information derived from many different sources to achieve its ends. V5 is only one of the elements in the vast machinery that the cerebral cortex has created to acquire a knowledge about this world. The results of its operations are relayed to other visual areas, which have their own specializations.

Conclusion

In the last few pages, we have tried to use kinetic art and its development as a means of illustrating our general point that, in creating his art, the artist unknowingly undertakes an experiment in which he studies the organization of the visual brain. We have tried to analyse kinetic art in terms of the known neurology of the brain in general and of the pathways subserving visual motion in particular. We have shown that area V5 must be critical for kinetic art. We have therefore also shown that it is possible to relate the experience of kinetic art to the healthy activation of small parts of the brain. We do not mean to imply that the resulting aesthetic experience is due solely to the activity of V5 but only that V5 is necessary for it. It is perhaps a measure of how far we have come along in visual physiology that we can do so and can also begin to enquire into the relationship between physiology and visual art. It goes without saying that there is much in kinetic art which we have left unexplored, even at this level, and there is much at a higher level which we are not even competent to explore. The relationship of brain organization to aesthetics, the symbolism inherent not only in kinetic art, but in all art, the relationship of art to sexual impulses — these are all subjects which are worthy of study,

though in a millennial future when we have learned a great deal more about the brain. In other ways, however, the millennial future which poets and artists have dreamed about is already here and, however small our contribution, it is satisfying to us to try to formulate the beginnings of an understanding of the relationship between the organization of the brain and its manifestation in art.

Acknowledgements

We wish to thank J. Z. Young, Diane Michener, Ray Guillery and other colleagues who read and commented on earlier versions of the manuscript. We benefited greatly from visiting three important exhibitions: 'The Great Utopia', an exhibition of Russian Constructivism at the Guggenheim Museum, New York (1992), the Marcel Duchamp Retrospective at the Palazzo Grassi in Venice (1993) and the superlative exhibition entitled 'l'Art en mouvement', organized by M. Jean-Louis Prat at the Fondation Maeght in St Paul de Vence during the summer of 1992. We record our appreciation of M. Prat's generous invitation. The laboratory is supported by grants from the Wellcome Trust.

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*Received June 28, 1993. Revised December 21, 1993.
Accepted February 28, 1994*