European breeds, the only modification to the foregoing opinions would be that a judicious infusion of European 'blood' may introduce desirable characteristics to some local breeds. This has become much easier with the development of artificial insemination, and it is now realized[1,2] that the stabilization of suitable hybrid cattle is far easier than had been supposed. Thus, over much of Queensland, which stretches from latitude 29° to 10° S., the best adapted hybrids will probably vary from three-eighths to five-eighths Brahman 'blood' and it is very unlikely that there will ever be large commercial herds of pure Brahmans. In the same way, suitable experiments and observations could lead to decisions concerning the correct admixture in other tropical areas, and this could move more towards the European breeds with improvements in disease control and agricultural practice.

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SEEING IN DEPTH

By R. L. GREGORY

The Psychology Laboratory, University of Cambridge

EYES are biological early warning systems. By giving information of events distant in space they serve to probe the immediate future, allowing brains to transcend simple reflexes and control strategic behaviour. Without information of distant objects there can be no anticipation of danger, no organized attack, no knowledge of the world. Indeed, the development of brains must have depended on seeing in depth.

The brain has a most difficult task interpreting retinal information from distant objects. The retinal image has lost a dimension: somehow the brain must construct depth from the projection of three dimensions reduced to two. For near objects the different views of the two eyes are used to compute depth, but the base line between the eyes is too small for distances beyond 50 ft. or so, when we are effectively one-eyed. With a single eye we generally see the world more or less accurately in three dimensions. For distant objects we use many 'clues' to depth, with a subtlety in the best traditions of the sleuth. With increasing distance, outlines look more blurred and fine detail is lost, objects look blue from increasing atmospheric haze, and more distant objects are in part hidden by those nearer the observer. These are some of the available clues to depth.

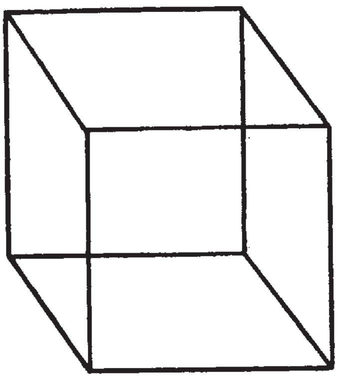

Fig. 1. The Necker cube. This spontaneously reverses in depth. There is no information available for deciding which is the nearer and which the further face. The perceptual system entertains first one hypothesis, then the other. The brain never makes up its mind!

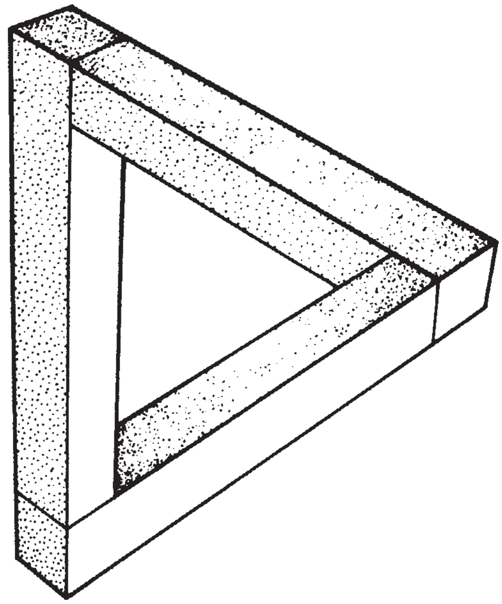

Fig. 2. An impossible object. This cannot represent any possible physical object, for it has conflicting depth 'cues' (after L. S. and R. Penrose, *Brit. J. Psychol.*, **49**, 31 (1958)

One can see why perception of depth is so difficult by thinking about pictures. Although a picture is itself two-dimensional, it represents objects lying in three dimensions. But this is strictly impossible, and so pictures are essentially ambiguous in depth. Consider a drawing of a simple ellipse: Is the object represented distant and large, or small and near? Is it an elliptical object, or a circle tilted at an angle? The two-dimensional drawing could represent any of an infinite set of objects. Add shading, perspective—or an indication that it is a wheel—then we see one specific object. Visual ambiguity in depth is seen dramatically in figures which could equally well lie in more than one orientation. For example, Fig. 1: a flat drawing of a skeleton cube. A given face is seen first as the front, then the back. The alternative 'hypotheses' are entertained perceptually in turn, and we never do see the figure as a unique unchanging object.

Pictures are not only ambiguous ; they are also paradoxical. A picture is seen to be lying flat on its paper or canvas, and yet is also seen in three dimensions as indicated by its perspective and other depth cues. It is paradoxical in being seen as both flat and in depth at the same time. Conflicting cues to depth can produce 'impossible objects'. Fig. 2 cannot be an object lying in space. Fig. 3 cannot even be seen. In both cases, the trouble is over the third dimension.

Why should the eye accept a picture as representing objects lying in a space different from its own ? It does so because a picture is essentially like a retinal image—both are flat projections of three-dimensional space. Pictures give simplified images, and very likely distorted in various ways, but the brain is so familiar with the problem of adding the third dimension from information given by the flat retinal image that we might expect it to cope with pictures. But there is an important difference between pictures and retinal images. Both are ambiguous, but retinal images do not lie perceptually in both two and three dimensions. We do not 'see' the flatness of the retina, or its texture : they are not signalled to the brain. Thus the brain has a more difficult task dealing with a picture than with normal objects. The textured background imposes a highly artificial problem to the visual system which it cannot completely solve. It is indeed unfortunate that experiments in perception have largely used figures drawn on paper. It is only when the double reality of the picture and what it represents is being explicitly investigated that pictures should be used in visual experiments.

It is, however, possible to produce pictures which, like retinal images, have no information of their flatness. This we may do by avoiding all background texture, and viewing with a single eye. When Fig. 1 is shown in this way—luminous, glowing in the dark—it appears as a truly three-dimensional cube. It still reverses in depth—it is still ambiguous—but it is no longer paradoxical in depth. The luminous figure looks different in another way—the apparently further face always looks larger than the apparently nearer face, whichever this may be. We see this distortion most dramatically in a truly three-dimensional skeleton cube, made of wire and coated with luminous paint to make it glow in the dark. The true cube also reverses in depth, and when it reverses it changes shape—the apparent front appearing too small. It becomes a truncated pyramid. Also, it rotates in the most odd way when the observer moves round it, but that is another story[1,2].

Why should the luminous cube change shape when reversed in visual depth ? This is answered by asking a silly-sounding question—why does a cube normally look like a cube ? This needs some explanation, for since the

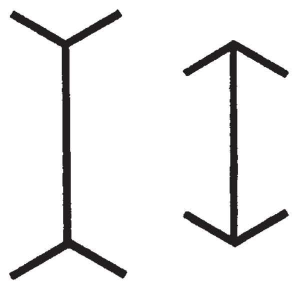

Fig. 4. The Muller-Lyer arrow illusion. Outgoing fins expand the shaft joining them, the ingoing shrink it. The 'fins' can be regarded as perspective lines of corners. When shown with no textured background (luminous) they look like true corners. The perspective depth appears to produce the illusion by triggering primary constance scaling

back face is further away, it must give a smaller image to the retina. But it does not look smaller—it looks the same size as the front. Although all objects give smaller retinal images as they recede from the eye, this geometrical shrinking is generally compensated by the brain, to give 'size constancy'. Size constancy was known to Descartes[3] in the seventeenth century, and has been investigated intensively since, notably by R. H. Thouless[4] in the 'thirties. It serves to give immediate recognition that a distant bottle is pint or half-pint, or whether it is a cat or a tiger about to spring. There are various theories about constancy[5,6], but I believe it to be produced by an active scaling process in the brain, either set according to the apparent distance of viewed objects or set directly by various depth cues. We may call the underlying processes 'constancy scaling'.

When we see the skeleton wire cube distorted, when reversed in depth, we see our constancy scaling at work. But it is working backwards. For it is working according to the apparent and not the true depth of the object. Although constancy scaling normally corrects for the shrinking of retinal images with distance, reversal of depth makes the normally useful compensation distort visual space. The cube looks more distorted than it would if there were no constancy scaling correcting for the shrinking of the image with distance. These distortions occur whenever depth reverses in non-paradoxical figures. It could happen in real conditions, such as landing aircraft, or in space flight, and the consequences might be serious[7].

The 'Geometrical Illusions'

We know, then, that visual space is distorted when depth is seen wrongly. Can this somehow explain the distortions of the well-known 'illusion figures' ? Fig. 4 shows the most familiar example: the outgoing arrow heads expand the line (or the space) between them, while the ingoing heads shrink it. Now these 'arrow heads' can be thought of as perspective drawings of corners lying in depth. They are the same shape as the retinal images of real corners[8]. With the outgoing arrow heads the vertical line would be distant, the heads representing, for example, the lines of the ceiling and walls of the inside corner of a room. The ingoing heads are perspective drawings of an outside corner, say, of a building or box, where the joining line would be near.

If the perspective features of retinal images do indeed serve to set constancy scaling, then when these features are present in flat pictures we must expect them to produce distortions of visual space. Constancy scaling corrects for shrinking of the retinal image with increasing distance, but pictures present perspective depth features with no

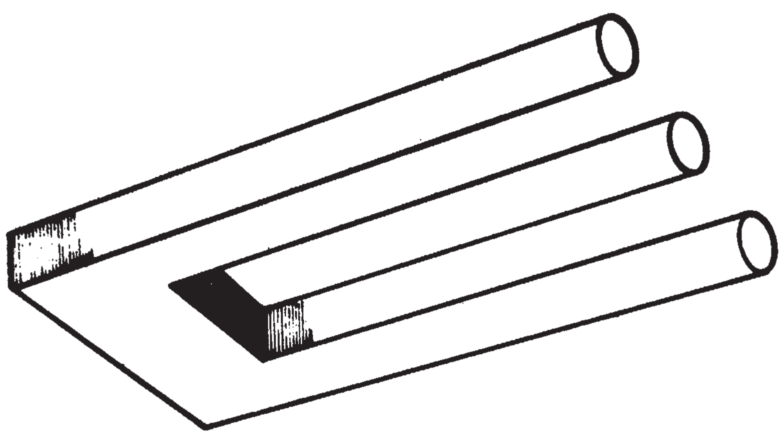

Fig. 3. This figure cannot even be seen. Again the difficulty is over the third dimension

change in distance to compensate, since they are physically flat, and so the scaling must be inappropriate. We must expect objects indicated as further away to be systematically expanded[9]. This is just what happens, apparently for all the illusion figures, with people familiar with corners and parallel lines.

It has been known for sixty years that people who live in environments largely free of right angular corners and parallel lines—such as the Zulus, who live in a 'circular culture' of round huts—do not suffer these distortion-illusions[10]. Miss Jean Wallace and I found that a man of middle-age, who recovered his sight by corneal graft after being blind since early infancy, was not subject to the illusions[11]. His perception of depth was also most odd. It seems that early experience of perspective features is important : apparently we learn to use perspective for setting constancy scaling.

Can we demonstrate experimentally a close connexion between depth and distortion illusions ? There are several hints in the literature of such an origin of the illusions[8,12], but there is a difficulty. It is always assumed that size constancy works simply according to apparent distance[5] (which is indeed true for the luminous cubes), but if this were always the case it could not produce distortions in figures seen as flat. But the illusion figures are generally seen as lying flat on their paper backgrounds, so how can we invoke constancy to account for these distortions ?

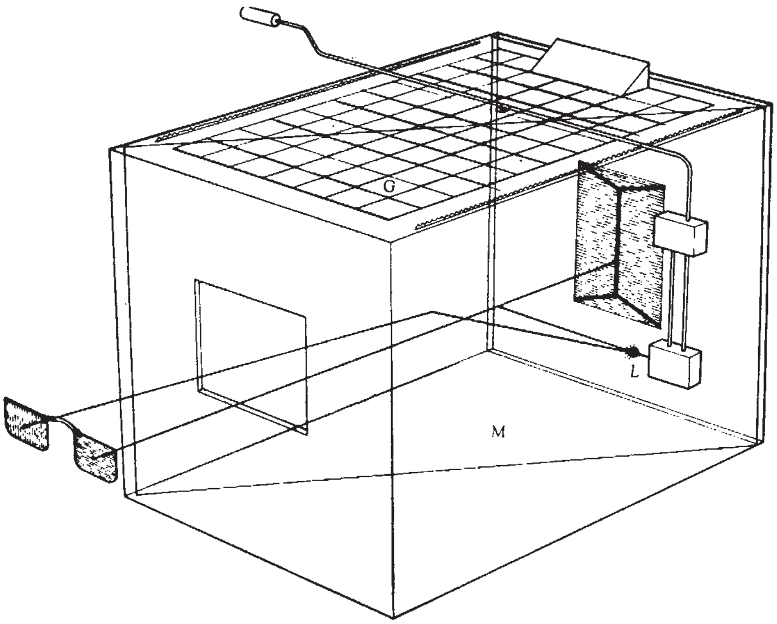

Fig. 5. Apparatus for measuring visual depth in pictures. The picture (for example, an illusion figure) is back-illuminated, to avoid background texture. It is seen monocularly, the light being polarized, and cross-polarized at one eye. The reference lamp (*L*) is seen by both eyes, by reflexion from the part-reflecting mirror (*M*), and is seen as lying in the picture. Its distance is adjusted to equal the apparent distance of any selected feature of the picture. Positions are marked on the graph paper (*G*), giving a plot of visual space in three dimensions (Gregory and Townes)

Measuring Depth in Pictures

The apparatus is shown in Fig. 5. The illusion figure is presented as a back-illuminated transparency. Light from it is polarized, and cross-polarized at one eye. Both eyes, however, view a small dim movable light which is optically introduced into the figure with a part-reflecting mirror. Now this light may be adjusted in distance, until it matches the apparent distance of any selected part of the figure seen with a single eye. The figure's depth is given by its perspective features, but the light's distance is given by convergence of the two eyes. Positions of the light are recorded on the graph paper at the top of the apparatus, and so we plot visual space in three dimensions, using the two eyes as a range-finder to measure the effect of perspective on a single eye. Fig. 6 shows how the arrow illusion is related to its apparent depth, as measured with this technique. The similarity of the distortion and depth functions, for various angles of the fins, demonstrates the close relationship we should expect—if indeed perspective features can set constancy scaling—to produce illusions when the perspective is inappropriate to true distance.

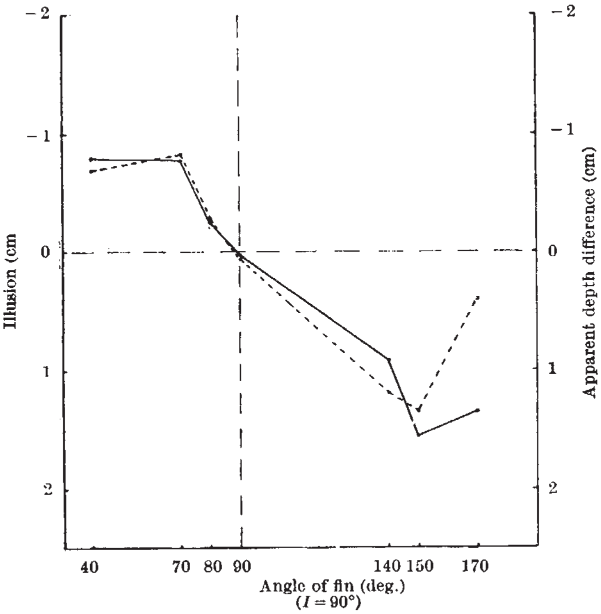

Fig. 6. Full line shows extent of Muller-Lyer arrow illusion (measured by adjusting a 'neutral' line to apparent equality) for a range of fin angles. Figures presented without background texture, to a single eye. The depth (broken line) is the difference in apparent distance between the shaft and ends of the fins

Depth Optics

Can we improve instruments, or devise new instruments, for extending the eye's ability to see in depth ?

The microscope is a direct extension of the eye, extending its ability to see the very small by effectively making it see objects extremely near. But when used at high magnification, its depth of focus is so small that structures lying only a few microns further or nearer the plane of sharpest focus are degenerated to be unrecognizable. It cannot provide the separated views to the two eyes to give stereoscopic depth. This limitation, however, can be overcome[13,14] by vibrating the objective lens of the microscope so that the plane of sharp focus scans rapidly up and down through the specimen, extracting the depth information with each scan. But if this were presented on a plane we would see confusion, for we would be compressing three into two dimensions. Somehow the information must be reconstituted into three-dimensional visual space. This can be done by projecting the image on to a screen kept vibrating in phase with the scan through the specimen. The image on the vibrating screen then changes systematically as it moves to and from the observer, and builds in the volume swept by the screen a 'solid image', magnified in depth. We can see, for example, brain cells magnified a thousand times in three dimensions. In practice the vibrating screen introduces difficulties, but it can be replaced by a rotating helical screen, or a screen avoided altogether, by sweeping the pair of images in opposition across the eyes, in a way the observer's brain accepts as signalling depth.

Could we devise a way of drawing pictures in three dimensions? Do artists have to be for ever limited to flat planes on paper? The problem is to produce a pair of lines, one for each eye, produced under the control of the artist, so that correct stereoscopic depth is given by the horizontal separation of the lines. We have recently built just such a device. The depth artist holds a stylus, bearing a small bright light which is imaged on a pair of Thorn electroluminescent image-retaining panels. As he draws with the light, in three dimensions, glowing lines are presented to each eye and fused by the brain into a single picture in depth. He sees and creates in a three-dimensional world, where artist and scientist meet.

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NEWS and VIEWS

The Royal Society: S. G. Brown Award and Medal

THE Royal Society's S. G. Brown Award and Medal has been won this year by Mr. F. T. Bacon, consultant to Energy Conversion, Ltd., for his work in the development of fuel cells, on which he has been continuously engaged for the past twenty years. The award is made annually by the Council of the Royal Society, on the nomination in turn of the Institutions of Civil, Mechanical and Electrical Engineers, for an outstanding contribution to the promotion and development of mechanical inventions. The nomination is based on work carried out during the year of the Award and the preceding five years. The 1965 nomination was made by the Institution of Mechanical Engineers, of which Mr. Bacon is an Associate Member.

Prof. A. C. Haddow, F.R.S.

THE cross of Chevalier de la Légion d'Honneur has been awarded to Prof. Alexander Haddow, director of the Chester Beatty Research Institute of the Institute of Cancer Research, London. This award is an indication of the esteem in which Prof. Haddow is held in scientific circles in France and is at the same time an expression of appreciation of much friendly collaboration over many years. Recently, Prof. Haddow has been closely associated with discussions about the international support of cancer research, in particular with the proposals put forward two years ago by the French Government.

Space Research in the Ministry of Aviation: Mr. J. G. Lewis

MR. J. G. LEWIS has been appointed director (space) at the Ministry of Aviation Headquarters in succession to Mr. C. J. Stephens, who is now attending the Imperial Defence College. Mr. Lewis was born in Skipton, Yorkshire, in 1921 and educated at Skipton Grammar School and later at Christ's College, Cambridge, where he specialized in mathematics and physics. In 1942 he entered the Air Defence and Research Establishment at Malvern (now the Royal Radar Establishment), where he worked on searchlights control and surveillance radars. In 1956 he attended the 17th course at the Joint Services Staff College. He was promoted to senior principal scientific officer in 1957 when, as superintendent of the Special Projects Branch at the Royal Armament Research and Development Establishment in Kent, he became more directly involved in the development of guided weapons. For the past three years he has been an assistant director in the Defence Research Staff in Washington, D.C., concerned with U.S. guided weapons and space activities and Anglo-American co-operative programmes.

Psychology in the University College of Swansea: Prof. C. E. M. Hansel

MR. C. E. M. HANSEL, who has been on the staff of the Department of Psychology in the University of Manchester since 1949, has been appointed to the newly established chair of psychology in the University College of Swansea. Mr. Hansel was born in 1917 and educated at Bedford School. From 1938 until 1946 he served in the Royal Air Force and reached the rank of squadron leader. After demobilization he proceeded to Fitzwilliam House, Cambridge, where he read psychology in Part II of the Moral Sciences Tripos. His principal research interests have been in the field of visual perception and, in particular, he has been developing a theory intended to integrate the physical and psychological phenomena of colour vision. In this sphere he is an authority. He has recently designed a new type of teaching machine. He has also excelled as the leading critic of the experimental basis of claims for extra-sensory perception. His thorough-going examination of this field of enquiry is to be published in the spring of 1966 (by Scribners, of New York) and will, no doubt, create considerable consternation among parapsychologists and their adherents. The topic will now be placed in its correct scientific perspective. While at Manchester, Mr. Hansel collaborated with Prof. John Cohen in researches into subjective probability, temporal phenomena, the spread of ideas, and other topics. This resulted in a joint book, *Risk and Gambling* (1956), and numerous papers on decision-making, the measurement of linguistic usage, and the *kappa* effect. Mr. Hansel is a talented musician, and for many years played first violin in the Alderley Edge Orchestra.

Second Chair of Electrical Engineering in the College of Advanced Technology, Birmingham: Prof. J. E. Flood

DR. J. E. FLOOD has been appointed to the second chair of electrical engineering at the College of Advanced Technology, Birmingham. He gained his initial education at the City of London School and then went on to take an engineering course at Queen Mary College. After war-time service at the Admiralty Signal Establishment, he joined the Research Laboratories of the British Post Office and for the next five years was occupied with the application of electronics to automatic telephone switching. Deciding to get nearer the product, he joined the then Siemens Brothers of Woolwich, now the Telecommunications Division of Associated Electrical Industries, Ltd. Here he took an active part in furthering electronic applications to the telephone and, for a number of years, was chief engineer of the Advanced Development Laboratories