bees' brain, and those lacking flower-vision die for lack of honey. So here is a mixture of innate and learned knowledge.

It is hard to establish what knowledge human infants are born with and what has to be learned. The difficulties are that there are strict limits to experiments that can be tried on human babies, and that infants have extremely limited co-ordinated behaviour. Until recently, almost all we knew of learning how to see has came from young animals. Now, however, there are safe and effective techniques for learning from babies what they can see. We will consider these new techniques and findings a little later, after looking at some physiological effects of experience on animals—and at some other matters—including what it is like to recover when adult from infant blindness.

Physiological changes

Recent experiments have been aimed at whether physiological 'feature detectors' (Figure 4.7) are simply given innately, or whether early experience affects them. Kittens have been reared in environments of vertical stripes, then tested for vision of vertical and other orientations. It has been found, especially by Colin Blakemore, that kittens living in a world of only vertical stripes appear to be blind to horizontal lines—and they lack horizontal feature detectors. Similarly, kittens denied vertical stripes do not have well organized vertical feature detectors. This suggests that feature detectors are not completely laid down at birth; but are developed—or 'tuned'—by visual stimulation encountered by the individual. This is important for considering optimal environments for babies, especially as it has been found that some innately given neural mechanisms degenerate with lack of stimulation. This is clearly so for the ability to see depth stereoscopically. In childhood there are 'critical periods' for learning how to see, and without suitable experience at the right time such visual skills can be lost forever. Early visual environment of babies is highly important for adult vision—so nursery wallpaper should be considered!

Adaptation to disturbed images

Displaced images

To discover mechanisms of perceptual learning, we may look at experiments on animals and humans fitted with optical systems of various kinds to modify the retinal image, and see whether eye and brain compensate or adapt to the changed input. This was first tried at the end of the nineteenth century in famous experiments by the American psychologist G. M. Stratton, on himself. But first, let's look briefly at animal experiments of this kind.

Inverting goggles placed on a monkey had the effect of immobilizing her for several days: she simply refused to move. When finally she did move it was backwards—a point of some interest as these inverting goggles tend to reverse depth perception. Similar experiments have also been tried in chickens and hens. Right–left reversing prisms were attached to the eyes of hens by M. H. Pfister, who observed their ability to peck grain. The hens' behaviour was severely disturbed, and they showed no real improvement after three months wearing the prisms. The same lack of adaptation has also been found in amphibia, by R. W. Sperry. With vision rotated through 180°, it was found that they would move their tongue in the wrong direction for food, and would have starved to death had they been left to fend for themselves. Similar results were also obtained by A. Hess with chickens wearing wedge prisms which did not reverse the images, but shifted them by 7° to the right or to the left. He found that the chickens would always peck to the side of the grain, and that they never adapted to the shift of the image caused by the wedge prisms. Hess concluded:

> Apparently the innate picture which the chick has of the location of objects in its visual world cannot be modified through learning if what is required is that the chick learns to perform a response which is antagonistic to its instinctive one.

It seems clear from the various experiments that animals show far less adaptation to a shift or reversal of the image than do human observers. Indeed, only monkeys and humans show any perceptual adaptation to these changes.

Now let's look at the classical work of G. M. Stratton on inversion of the retinal image for a human observer. He wore inverting goggles for days on end—and was the first man to have retinal images that were *not* upside down! He devised a variety of lens and mirror systems including special telescopes mounted on spectacle frames so they could be worn continuously. These generally inverted both vertically and horizontally. Stratton found that when a pair of inverting lenses was worn giving binocular vision the strain was too great as normal convergence was upset, and this did not adapt to the situation. He therefore wore a reversing telescope on just one eye, keeping the other covered. When not wearing the inverted lenses he would keep both eyes covered, or stay in a dark room. He slept in the dark.

At first, objects seemed illusory and unreal. Stratton wrote (1896–7):

. . . the memory images brought over from normal vision still continued to be the standard and criterion of reality. Things were thus seen in one way and thought of in a far different way. This held true also for my body. For the parts of my body were felt to be where they would have appeared had the instrument (the inverting lens) been removed; they were seen to be in another position. But the older tactual and visual location was still the real location.

Later, however, objects would look almost normal.

Stratton's first experiment lasted three days, during which time he wore the 'instrument' for about 21 hours. He concluded:

I might almost say that the main problem—that of the importance of the inversion of the retinal image for upright vision—had received from the experiment a full solution. For if the inversion of the retinal image were absolutely necessary for upright vision . . . it is difficult to understand how the scene as a whole could even temporarily have appeared upright when the retinal image was not inverted.

Objects only occasionally looked normal, however, and so Stratton undertook a second experiment with his monocular inverting arrangement, this time wearing it for eight days. On the *third day* he wrote:

Walking through the narrow spaces between pieces of furniture required much less care than hitherto. I could watch my hands as they wrote, without hesitating or becoming embarrassed thereby.

On the *fourth day* he found it easier to select the correct hand, which had proved particularly difficult:

When I looked at my legs and arms, or even when I reinforced my effort of attention on the new visual representation, then what I saw seemed rather upright than inverted.

By the *fifth day*, Stratton could walk around the house with ease. When he was moving around actively, things seemed almost normal, but when he gave them careful examination they tended to be inverted. Parts of his own body seemed in the wrong place, particularly his shoulders, which of course he could not see. But by the evening of the *seventh day* he enjoyed for the first time the beauty of the scene on his evening walk.

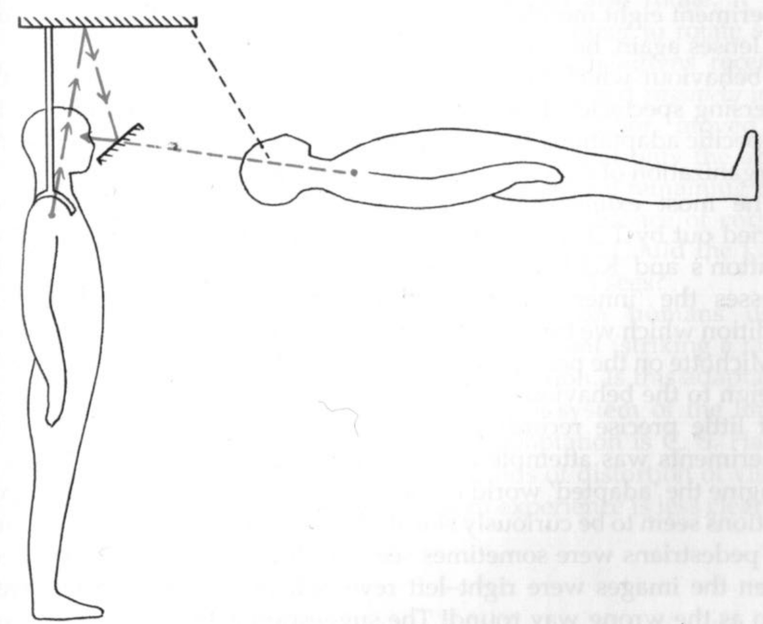
On the *eighth day* he removed the inverting spectacles, finding that:

. . . the scene had a strange familiarity. The visual arrangement was immediately recognised as the old one of pre-experimental days; yet the reversal of everything from the order to which I had grown accustomed during the last week, gave the scene a surprising bewildering air which lasted for several hours. It was hardly the feeling, though, that things were upside down.

One has the impression when reading the accounts of Stratton, and the investigators who followed him, that there is always something queer about their visual world though they have the greatest difficulty saying just what is wrong with it. Perhaps, rather than their inverted world becoming entirely normal, they cease to notice how odd it is until their attention is drawn to some special feature, when it does look clearly wrong. Thus writing appears in the right place in the visual field, and at first sight looks like normal writing, except that when they attempt to read it, it is seen as inverted, or at least it appears odd.

Stratton went on to perform other experiments, which though less well known are just as interesting. He devised a mirror arrangement, mounted in a harness (Figure 8.1), which visually displaced his own body so it appeared horizontally in front of him at the height of his eyes. Stratton wore this mirror arrangement for three days (about 24 hours of vision), reporting:

The different sense-perceptions, whatever may be the ultimate course of their extension, are organised into one harmonious spatial system. The harmony is found to consist in having our experience meet our expectations . . . The



8.1 Stratton's experiment, in which he saw himself suspended in space before his eyes, in a mirror. He went for country walks wearing this arrangement.

essential conditions of the harmony are merely those which are necessary to build up a reliable cross-reference between the two senses. This view, which was first based on the results with the inverting senses, is now given wider interpretation, since it seems evident from the later experiment that a given tactual position may have its correlated visual place not only in any direction, but also at any distance in the visual field.

Several investigators have followed up Stratton's work. G. C. Brown used prisms to rotate the field of both eyes through 75°, and found that this reduced the efficiency of depth perception; but there was little or no evidence of improvement with experience, though he and his subjects did find that they got used to their tilted world. Later, P. H. Ewert repeated Stratton's experiment using a pair of inverting lenses, in spite of the strain on the eyes found by Stratton. Ewert's work has the great merit that he made systematic and objective measures of his subjects' ability to locate objects. He concluded that Stratton somewhat exaggerated the amount of adaptation that occurred. This led to a controversy that is still unresolved.

The problem was taken up by J. Paterson and J. K. Paterson, using a binocular system similar to Ewert's. After 14 days they did not find complete adaptation to the situation. Upon re-testing the subject of the experiment eight months later, they found that when the subject wore the lenses again, he immediately showed the various modifications to his behaviour which he had previously developed while wearing the reversing spectacles. It seemed that the learning consisted of a series of specific adaptations, overlying the original perception, rather than a reorganization of the entire perceptual system.

The most extensive recent experiments on humans have been carried out by T. Erisman, followed by Ivo Kohler at Innsbruck. Both Stratton's and Kohler's experiments rely on verbal reports. Kohler stresses the 'inner world' of perception, following the European tradition which we find in the German Gestalt writers, and in the work of Michotte on the perception of causality (Chapter 4). This emphasis is foreign to the behaviourist tradition of America, and it is unfortunate that little precise recording of the subject's movements during the experiments was attempted. From the verbal reports it is difficult to imagine the 'adapted' world of the experimental subjects, for their perceptions seem to be curiously shuffled and even paradoxical. For example pedestrians were sometimes seen on the correct side of the street, when the images were right–left reversed, though their *clothes* were seen as the wrong way round! The suggestion is that having to avoid bumping into people produced re-learning of their positions on the pavement, but not of which side the buttons were on their coats. Writing

is one of the more puzzling things observed. With right–left reversal a scene would come to look correct, except that at least sometimes writing remained right–left reversed and hard to read.

Touch had important effects on vision: during the early stages of adaptation objects would tend to look suddenly normal when touched, and they would also tend to look normal when the reversal was physically impossible or highly unlikely. For example, a candle would look upside down until lighted, when it would suddenly look normal—the flame going upwards, instead of downwards. Touch, even with a long stick, would switch the world the right way up.

There is later evidence, mainly from the work of Richard Held and his associates, particularly Alan Hein at M.I.T., to show that for compensation to displaced images to occur, it is important for the subject to make active corrective movements. Held considers that active movement is vital for perceptual learning in the first place, as well as for compensation. An experiment with kittens is particularly ingenious and interesting. They brought up a pair of kittens in darkness; they could see only in the experimental situation, in which one kitten served as a control for the other. The two kittens were placed in baskets attached to opposite ends of a pivoted beam, which could swing round its centre, while the baskets could also rotate. It was arranged that a rotation of one basket caused the other to rotate similarly (Figure 8.2). With this ingenious device both kittens received much the same visual stimulation, but one was carried *passively* in its basket; the other, whose limbs could touch the floor, moved the apparatus around *actively*. Held and Hein found that only the active kitten gave evidence of perception, the passive animal remaining for a time effectively blind. But is this 'blindness' the absence of correlations built up between its vision and its behaviour? Could the kitten indeed be seeing, but be unable to let us know that it sees?

Richard Held also undertook experiments on humans using deviating prisms, finding that active arm movement (striking a target with the finger) is necessary for effective adaptation. Is this adaptation *perceptual*, or is it *proprioceptive*—in the control system of the limbs? The principal supporter of proprioceptive adaptation is C. S. Harris. This cannot apply to adaptation to some kinds of distortion of vision, and in these cases the role of feedback from experience is less clear.

Distorted images

We have considered experiments on inverting and tilting the eye's images, but other kinds of disturbance can be produced, which are