Looking at Radiographs

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SUMMARY

'As one who hangs down-bending from the side
Of a slow-moving boat, upon the breast
Of a still water, solacing himself
With such discoveries as his eye can make
Beneath him in the bottom of the deep,
Sees many beauteous sights — weeds, fishes, flowers,
Grots, pebbles, roots of trees, and fancies more,
Yet often is perplexed and cannot part
The shadow from the substance, rocks and sky,
Mountains and clouds, reflected in the depth
Of the clear flood, from things which there abide
In their true dwelling; now is crossed by gleam
Of his own image....'

William Wordsworth — The Prelude: 'Summer vacation'


Two very important technical innovations have arrived on the radiological scene during the past decade. Computed tomography and ultrasound are powerful diagnostic techniques with a wide range of application. In image production there are, of course, fundamental differences between conventional radiology, computerized tomography and ultrasound. Xerography is yet another imaging technique particularly suitable for soft-tissue radiography. The radiologist must be able to read TV images constructed of hundreds of pixsels, as in computerized tomography, Xerox prints, or Polaroid reproductions of ultrasound TV images, in addition to conventional X-ray films and TV-monitored fluoroscopy. But whatever the technique, they all have one thing in common, namely the perception and interpretation of contrasts and densities. All doctors depend, to some extent, on their visual faculties in order to make a diagnosis, and the majority of doctors regularly look at X-ray films, but the physiology of vision, perception and interpretation is of particular interest and concern to the radiologist. It is the basis of all his work.

In contrast to the tremendous technical advances there is a relative lack of information on the image-retina-cortex pathway. Ten years ago one entire edition of Radiologic Clinics of North America was devoted to 'Perception of the roentgen image' (December 1969). This volume contains a number of excellent articles.

Much research has been done, however, into the physiology of visual perception, as is evident from the many publications in various non-medical scientific journals. A great deal has been published in summary form in Scientific American, e.g.: 'Contrast and spatial frequency', 'Perception of disorientated figures', 'Subjective contours', and many others, but no work seems to have been done during the past decade on radiology-related perception per se.

THE ENVIRONMENT

It is not only the physiology of perception with which we are concerned, but various factors which can affect perception and interpretation. To name a few: visual and auditory distractions in the environment, fatigue, level of vigilance and arousal, emotional state, degree of confidence, fear of making a wrong diagnosis, prior knowledge of clinical information, type of training, prejudices against certain films ('not another skull!') or subspecialties (e.g. trauma), motivation, boredom, medication, work pressure and interruptions. All these factors and perhaps many others, as yet undefined, must surely influence our film-reading ability, and some have been shown to do so. It will be up to radiologists themselves to implement their particular ideal training and working conditions in order to supply their colleagues with the maximum of reliable information.

ILLUSIONS AND AMBIGUITY

The physiology of vision is a fascinating subject and also extremely complex, in view of the evidence that perception involves the association cortex, which implies that it is part of the thought process and therefore much more than mere sensation. This makes sense embryologically, since the retina is part of the central nervous system. Properly speaking, the optic nerve is a tract. Optical illusions and ambiguous figures (well exploited by the Dutch graphic artist Maurits Echer) show that perception is not fully determined by sensory input. The two lines in Fig. 1 are identical in length, and the horizontal lines in Fig. 2 are straight. The duck in Fig. 3 (top) may also be interpreted as a rabbit if rotated 90°, and the attractive young lady (bottom) as an ugly old woman. Anderson' demonstrates how we automatically group objects according to proximity (Fig. 4(a)), and similarity and colour (Fig. 4(b)) ('perceptual grouping'). He finds that simplicity or simplification is an important element in perception, which means that where alternative perceptions are possible, the simpler will be perceived. When breaking down Fig. 5(a) into its components, solution 5(b) is always chosen. Cogel's 'adjacency principle' is like the simplicity principle.
in action, e.g. the rolling wheel, the only visible parts being several points of light on the rim and a single point at the hub. The trajectories for the absolute motions of the points would be a straight line for the hub and cycloid curves for the rim. Instead, we perceive the relative motions of these points which present a revolving disc on a straight course (Fig. 6).

Kanizsa' writes about subjective contours, i.e. physically non-existent contours supplied by the visual system. Three dots placed in relative proximity are always connected by straight lines to form a triangle. However, amorphous figures with curved subjective contours can also be created. He noted that the region bounded by the sub-
jective contours appears brighter than the background, and opaque and superimposed on other figures. In any picture some feature forms a figure, the others will recede into the background. How this happens will depend on physical energy (brightness and colour), spatial change, and emotional energy. When such a picture consists of only two areas, the smaller will always be seen as the figure (Fig. 7).'

Fig. 7. See text.

To what extent these so-called illusions affect our search pattern has not been explored. A well-known common source of error is due to inability to segregate embedded shadows or contours, which requires analysis of a two-dimensional image into three dimensions. This is probably due, in part, to ambiguity of the signal.'

MATCHING OR TESTING

It appears that vision is coherent without being a faithful reproduction, i.e. the retinal image, unlike a photographic image, is only a framework which is then filled in from a store of memories. This can be demonstrated by asking someone to scan a film rapidly and then describe the lesion from memory. An experienced radiologist is more likely to describe it in terms of a well-established memory pattern rather than to describe the lesion he has just seen. Or, to put it differently, one would recognize an image of the Mona Lisa even if it were extremely blurred or fragmented, because one's memory would fill in the gaps. Anderson' calls this process 'feature testing', in contrast to 'template matching'. Another example is given in Fig. 8, the legend of which is likely to be read as 'Paris in the springtime'.

Far from being a passive, focal mosaic, the retina has several other sophisticated functions such as contrast enhancement, movement detection, decision making, pattern recognition and information rejection. All these take place at retinal level, at least to some extent. Rodieck' found that the mechanism for contrast occurs as early as the ganglionic layer in the retina. Ganglion cells, whose axons make up the optic nerve, each have their own receptive field. During light stimulation of a single receptive field, on-centre cells are fired by light in the centre of the field and inhibited by light in their surrounds. The reverse applies to off-centre cells. The effect of this mechanism is to enhance contours. Ross' has demonstrated, by means of his random dot stereograms, that binocular perception has access to visual stores that are independent of what we see in order to determine the proper framework for perception. Some years before, Julesz' found that random dot patterns combine to form three-dimensional scenes when viewed with a stereoscope. This means that binocular depth perception can occur in the absence of monocular depth cues.

Fig. 8. See text.

EYE MOVEMENTS

When we look at a film, our eyes move rapidly in a series of saccades or jumps. In fact, this is essential to vision, as the focal angle is only 2°, which makes the visual field the size of a 5-cent piece at arm's length. Enoch' has established that 9° of visual angle is the optimum display size, and this closely approximates the 70-100-mm film size which is becoming more popular lately (also for economic reasons). Useful vision occurs only during fixations, and for somebody looking at an X-ray film these fixations last about 350 milliseconds. The dynamics of this process are outside conscious control, because even when we consciously decide to fixate a lesion, the eyes make many corrective saccades. There is, of course, continuous interplay between perception from previous visual fixations, foveal information and information from the peripheral retina. When eye movements are recorded by a camera the film search pattern is extremely random, without any semblance of the orderly search pattern which one has been taught to apply. Although the general search pattern is centrally controlled, individual eye movements are largely determined by peripheral retinal stimulation.' However, prior knowledge of the presence of a lesion does alter the search pattern of fixation into a more localized or complex form. Kundel and Wright' also confirmed what we know from personal experience, namely that the finding of a lesion tends to stop further searching. The clinical information which so alters our search behaviour is impossible to suppress once it has been received.'
LOOKING AND SEEING

Fixation is commonly unaccompanied by recognition or detection, i.e. looking without seeing is probably a common source of error. In one experiment subjects were asked to record changes on a dial. One-third of these changes were not recorded, although they had been fixed according to the eye movement record. Only a relatively small number of fixations ever become conscious, even though many fixations are accompanied by appropriate motor action for which there is no recall.

The rate of eye movement rises with heightened interest, and an interest in a film will probably raise the chances of finding a lesion. Young men's eyes, when looking at pictures of attractive young women, move twice as frequently as when inspecting ink blots. Also, there are fewer blinks and eyelids and pupils are wider than normal. This in itself is a good enough reason to show a particular film to an expert in that field.

PERCEPTION

Anderson analyses perception into primary and secondary types. He defines primary perception as the collection of information within the presence, and secondary perception as collation of current information with memory. The latter, he finds, has three important functions: (i) selection and rejection of features; (ii) combination of features (dependent on learning); and (iii) enrichment which is going beyond the information and supplementing it with information from the memory store. He makes the relevant observation that premature attempts to identify a stimulus can produce interpretations which actually delay the final identification. He demonstrated this by asking subjects to interpret pictures projected out of focus. Those who started interpreting the farthest out of focus required the highest degree of final focus for identification.

The mechanism of visual perception also affects our thought, i.e. our thinking is stimulus-bound. It seems to be almost impossible to think coherently with eyes closed. Our thinking is then influenced by internal memory images which are usually irrelevant and confusing.

NOISE

How does noise influence our image-reading ability? In a broad sense noise includes any type of environmental disturbance, inappropriate memories in the radiologist's brain and irrelevant statements on the request form, apart from the ever-present auditory and visual noise. Many of these factors probably have a variable effect, with very subjective qualities. Personal opinions vary widely, owing to lack of concrete evidence. Interruptions during any kind of concentrated activity are probably widely accepted as undesirable. But how many radiologists do in fact insist on not being interrupted while reporting or screening?

In experiments relating to vigilance and performance of antisubmarine warfare personnel, Broadbent found that auditory stimuli are only beneficial in preventing the subject from falling asleep. Beyond a certain level (unspecified) these stimuli had adverse effects.

Oswald, analysing the effect of fatigue on vigilance and performance, found that reaction times were prolonged, many stimuli were missed, responses were wrong, and information provided by past experience was ignored. This realization alone should provide ample inducement for taking sufficient time off to rest.

During World War II great strides were made in technical developments. Yet they were often found to be useless if no account was taken of human frailties. Experiments on motorists and traffic have shown that the ability to distinguish contrast deteriorates markedly with age, even in the presence of normal acuity. Glare, which is the scattering of light within the eye, increases with age and further reduces this contrast. Campbell and Maffei have studied aspects of contrast and conclude that loss of contrast perception is not so much due to a decrease in the relative brightness of adjacent areas as to a decrease in the spacing of adjacent areas. This is based on the observation that details of an object consist of contrasting areas, with a regular spacing or spatial frequency. The visual system is more sensitive to certain of these frequencies than to others. This may be the reason for the poor results of contrast-enhancing techniques and colour imaging, i.e. only inappropriate factors are being enhanced. The questionable value of such equipment was raised by Tuddenham, who found that many of the lesions missed on film-reading test runs, such as a mastectomy or dislocated shoulder, were perfectly obvious to the initiated. I recently persuaded nine radiology registrars to participate in some experimental film-reading sessions. Each was presented with one of two series of similar chest radiographs to be read in a quiet office, the other series being handed over for analysis in a noisy corridor (where in fact much of the departmental reporting is being done). They were asked not to attempt a diagnosis, but merely to record on paper at their own pace all positive signs, most of which were considered to be

Fig. 9. See text.
very obvious. Six of the nine registrars performed significantly better in quiet surroundings; in one the difference was equivocal. In other words, the number of misses was much greater in the noisy corridor. It is interesting to note that some of the most obvious signs were ignored in both locations. In Fig. 9 the right mastectomy was completely missed by eight registrars, although one did notice the abnormal axillary fold. Five observers failed to comment on the almost completely eroded right 6th rib, and seven registrars missed the narrow right main bronchus even though this is a relatively weak sign.

Apart from supplying the basis of decision-making, one's teaching is probably and perhaps inevitably a large source of noise. Some topics may have been badly taught and may forever remain a source of uncertainty or conflict. Wrong facts may have been taught, and unless these are untaught they will remain a potential source of error. Even more deleterious is prejudiced teaching. An off-the-cuff remark such as 'plain film of the abdomen is pretty useless' from a senior consultant to a junior registrar is very likely to create a lot of noise in the abdominal film search pattern until the initial impression is voluntarily eradicated, perhaps years later.

The ideal initial reaction to any unfamiliar shadow or contour on a film should be arousal of curiosity. However, if one observes oneself carefully, one notices that time and again one has perceived and then ignored certain shadows. This may be due to some environmental interference or poor short-term memory, but is often the result of subconscious avoidance of conflict and uncertainty in the face of an unfamiliar problem. In this respect feedback is important, in that it should reduce areas of uncertainty. In a less complex situation, feedback reduced search error in photo-interpreters, and Mackworth found that detection performance in radar operators improved when they were informed of the missed target.

Hardly anything is known about the personality type most suited for radiology. Mackworth, in his book *Vigilance and Habituation*, finds that introverts perform better than extroverts and smokers better than non-smokers! This observation applies to vigilance only.

Thomas' makes several useful suggestions in his article on 'search behaviour'. These include the provision of an environment free from distractions and interruptions, the searching of films before and after reading of the request form, repeat search sessions and comparison-reading by a colleague, the recording of abnormalities immediately when they are detected — this in view of our untrustworthy short-term memory — and, of course, the comparison of results with later clinical findings. Most radiologists probably use some elements of such an ideal pattern, if only intermittently, because of work pressure.

**CONCLUSION**

Conclusions which could be drawn at this stage could be applied to the teaching and practice of radiology. Teaching should of course be intensive, always factually correct, consistent, and without personal overtones. Programmed material (slide-tapes, etc.) is particularly suitable, as it may be repeated at will. Much as one has to rely on one's remarkably complex and adaptable visual system, one should be aware of its inherent weaknesses and the many circumstances which may affect its function adversely. As enrichment and matching are part of the whole process of perception, it follows that a continual process of image-storing and reinforcement is essential for good radiological perception. This is not a new idea, but it may have more momentum when placed on a film physiological basis. The emphasis should be on building up a large memory store of images by studying as vast a number of X-ray and other patterns as possible during the training years and beyond; this would, of course, require an almost infinite film library. Film patterns should be studied descriptively. Haber emphasizes that once the component parts of an image have been labelled by attaching words to pictorial detail, it can be recalled from memory much more completely.

Compared with most other specialties, radiologists have relatively little information at their disposal for making a diagnosis. Their search behaviour and decision-making require an unusually high degree of concentration if they are to be consistently reliable. Considerable perseverance may be required, particularly in a restless hospital environment, in order to create the type of atmosphere most suited to this work pattern, and proper motivation is probably the most important factor in reliable interpretation. Motivation, during the transitional training stage from medicine to pure radiology, accompanied largely as it is by physical removal from the patient, demands a great shift of emphasis. The new source of motivation may then be found in teaching, in maintaining a competitive spirit with colleagues, and in continually improving the standard of work.

Information on the psychophysiology of perception and the related aspects of the psychology of memory and problem-solving is continually becoming available. Analyzed and applied, it may well come to have a more important practical bearing on the teaching and practice of radiology. This could happen through a greater understanding of our behaviour and an awareness of our shortcomings, as well as through the evolution of better teaching methods and teaching aids. Such improvements would of course be applicable in all branches of medicine.

**REFERENCES**