THE PERIPHERAL RETINAL 'MAP'*

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ABSTRACT

The condition of the periphery of the retinal field of the human eye is of considerable significance, it is suggested, to those participating in various sporting activities. Its boundaries shrink and expand depending upon the physiological conditions imposed both upon the eye and upon the organism as a whole. Consequently its message to the brain may be impaired under stress with resulting danger owing to delayed response.

Introduction

The periphery of the retina constitutes a surprisingly large area especially when compared with the fovea and para-fovea (Fig. 3), yet it is represented anteriorly in the occipito-cortical region of the brain as relatively small and its visual acuity is of a uniformly low order as Fig. 1 reveals. Even so, it possesses one distinctly important characteristic and that is the facility of being able to perceive movement more accurately than within the central visual field. It was probably this quality which induced McCloy (1937) to delineate 'peripheral vision' as one of ten factors contributory to the performance of gross motor skills and others (Fleishman and Rich, 1963) to emphasise strongly the significance of visual-spatial abilities from among the audial-visual-manual triad in the initial stages of skill acquisition. Of course the eye is not unique as a sense organ in which brain tissue and receptors are intimately connected, but as an embryological outpouching of the brain (Brown, 1928) it would seem that visual messages are among the most complex and most important (Adrian, 1946) in an hierarchical 'Grand Chain of Being'.

Since the peripheral field comprises such a relatively large area, those who participate in both 'closed' and 'open' skills are often acutely aware of its significance. Thus the area to the rear of the throwing circles in shot, discus and hammer is sacrosanct to the performer as any aimlessly wandering official learns to his cost and as many opponents use to their advantage. The sprinter uses 'peripheral vision' to locate his rivals; the basketball player controls the ball within it whilst he scans the display; the hockey player takes evasive action as a menacing stick enters it during his dribble towards the circle. It is as though the periphery of the retina 'shouts' its message to the brain (Brindley, 1960). As information is relayed from without-inwards, that is, centripetally, it is effected physiologically, by the retinogeniculostriate pathway — the neural tract from

the receptor rods and cones, or first order neurones, through the bipolar cells (second order neurones) and ganglion cells (third order neurones) to the lateral geniculate body where neural messages from the eye are encoded (Clark, 1962) and conveyed by fourth order neurones to the cortex, in this instance, Brodmann's areas 17, 18, 19 of the area striata. This primary visual system is so elaborately organised as to be able to replicate in neural space the spatial relationships of the physical world of objects that we perceive. As in other sensory systems, this topological organization constitutes an important aspect of the neural mechanism of sensation and in consequence the health of the peripheral 'map' plays an integral part both in spatial orientation and in kineasthetic feedback.

Method

All tracings of the periphery of the retina were compiled by using the Hamblin Perimeter (Fig. 2) which eliminated eye/head movements since it required the subject to fixate the head by means of a chin rest. To the semi-circular arm of the Perimeter were enjoined two small, circular white markers each an eighth of an inch in diameter, one permanently affixed to the centre, the other able to be moved to the very limit of the arm by a controlling dial behind the apparatus and out of sight of the subject. The subject covered one eye and placed his chin on the appropriate part of the rest, focussing the fovea on the fixed spot and indicating by a call when the spot moving from the distal end of the arm (towards the arm end in test C) was just able to be detected entering his own peripheral field. A point was then inscribed on the chart and the arm moved through an arc of 15 degrees to repeat the process. The recording was conducted in complete darkness except for a small light which was directed away from the subject but illuminated the centre spot and perimeter arm. Such a perimeter is normally used by ophthalmic opticians to detect abnormalities in the visual fields of their patients.

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Pre- and post-test tracings were taken (cf. Figs. 3, 4, 5) and comparative histograms constructed of eight axes for each eye, viz. Superior (S), Temporal 45° (T45), Temporal (T), Temporal 135° (T135), Inferior (I), Nasal 135° (N135), Nasal (N), and Nasal 45° (N45), and the greatest percentage increase and decrease of each subject's eye noted (Table I). Homologous groupings were made under:

- A — Endurance exercise of increasing intensity.
- B — Fasting.
- C — Smooth tracking of the eye: dot moving outwards.
- D — Rhodopsin bleaching: six flashes of intense light each lasting 10 secs. followed by a 30 sec. interval.
- E — Vestibular stimuli: subject rotated 10 times on a turntable at the rate of 1 rotation per sec.
- F — Scotopic vision improved: subject allowed to adapt to the dark for 15 mins.

Discriminations between subjects and between activities are noted beneath each histogram on which are indicated pre-test, or normal, readings in solid lines, immediate post-test in broken lines. After the 3 mile run, subject A₆ imbibed 5 mls. 70% rum after studied and restrained retention in the mouth for one minute and subjects B₂ and B₆ each took 5 mls. and 15 mls. of water with their 3.5 grammes and 14 grammes of glucose respectively. Under strict test conditions it was possible to study the responses of a small homogeneous group of eight 'Wing' P.E. students whose ages ranged between 18-20 years, and all but one of whom possessed a more than average skill in one particular sport. However, it should be noted that this was an exploratory study rather than one of testing on an extensive scale. Subject A₁ was a typist, subject A₂ a schoolboy in his school's rowing eight and a green belt at Judo; subject A₃ was a 1st Dan, subject B a decathlete whilst subject C₃ was a housewife and subject C₄ her husband who kept his weight down with daily exercise. The sampling is thus variegated.

Results

Table I reveals empirical analyses for individual subjects and for the battery of tests as a whole. The highest recorded percentage increase is subject F₁ with an 85% expansion of the superior axis of the left eye whilst the greatest decrease is that of subject A₂ at 50% for the right eye, also along the superior axis. Startlingly contrasted are the increases in all the parameters of F₁ whilst those of his companion show only 7 axial decreases out of 16, emphasising that dark adaptation is very much an individualistic matter (Edholm, 1967) and can vary up to 40 minutes for full adaptation. The rate of adaptation might also suggest a proclivity towards

'Field Independence' (Witkin et al, 1954) on the part of F₂, a useful discus thrower and swimmer, who could depend more on senses other than the visual. Subject A₂, after only 10 mins. skipping, showed a diminution in eight out of a total sixteen axes, whereas A₁ revealed decreases in seven and those at a much lower percentage value. In each subject the hint is that habituation to a monotonous stimulus has resulted in decreases in peripheral attention.

The greatest axial incremental incidence throughout the tests in group A was found to be that of the Inferior Axis; for subject A₃ the 5.7% decrease in the right eye could be crucial in a sport where ashiwaza (foot-sweeps) and low throws, like taiotoshi (body drop), are common among judoka. Yet, ironically, it has been known for a blind player to gain his black belt at Judo by using tachiwaza (standing techniques) as well as osaekomiwaza (holding techniques).

Tests A₄, A₅, A₆ were carried out by the same subject who found distance running a chore. He did, however, appreciate the need for it as a concomitant to good performance in his chosen sport, Rugby football. Perhaps this is why there were not the substantial decreases as in A₂ but, in particular, a high nasal 135° increase of 33.3% in the right eye after the six mile run. Certainly the individual who lacks endurance and becomes fatigued has a tendency to disregard a potentially hazardous situation but the threshold of such fatigue may not necessarily be commensurate with peripheral retinal fatigue and after the distance running tests, temporal axes are seen to enlarge that range of small scale scanning (Lowenstein, 1966) in a task where the gaze may be expected to wander. It has been known for foveal acuity to increase as much as 45% within ten minutes following a 1000 metre race (Graybiel, Jokl and Trapp, 1955); it is possible that the periphery works in harmony by expanding along certain axes.

For those axes which suffered under the effects of anoxia and alcohol — and here the results of A₄ and A₆ are comparable — it would appear that blocking by the activities of the reticular formation lead to inhibition in the order: cortex, lateral geniculate nucleus, ganglion cells, bipolar cells and receptors. The dominance of the cortex in the control of the retina is noted. After only a small intake of alcohol decreases were also observed along seven axes including the important inferior axis of the right eye (A₆), whilst after an effort over twice the distance and following abstemtion, only five axes suffered and two of those only marginally with test A₅.

It was found that a depletion in basal metabolic rate through fasting was only temporarily returned to peripheral retinal normalcy along certain axes by the ingestion of a small quantity of glucose. After 30 minutes the effect had worn off (cf. B₁, B₂, B₃). But

following the 24 hr. fast and an intake of 14 grammes of glucose the peripheral 'map' returned to a more healthy state. This would endorse earlier work (Granger, 1959) but emphasises the need for massive doses of glucose during protracted events especially where visual orientation is important such as during the second day of a decathlon; hurdles, javelin (Whiting, 1969) and pole vault could suffer as a result of peripheral shrinkage. The

results show how much the left eye suffered and how dominant the right eye became (Fig. 4), if by dominance is implied a greater peripheral range. During the final stages of the 24 hr. fast the subject noted that vision was comparable to looking through a misty penumbra, the 'optical filter' noted by McFarland et al, (1944) and indicative of changes in the central nervous system as its metabolic support is withdrawn under conditions of physiological stress.

TABLE I

GROUP A		A ₁		A ₂		A ₃		A ₄		A ₅		A ₆
AXIS OF GREATEST % INCREASE FROM NORM.	LEFT I 10.2	RIGHT N 40.7	LEFT N135 48.1	RIGHT I 19.1	LEFT T45 13	RIGHT N135 33.3	LEFT I 17.4	RIGHT N135 14.8	LEFT I 13	RIGHT N135 33.3	LEFT N135 24.3	RIGHT T45 18.4
AXIS OF GREATEST % DECREASE FROM NORM.	N 19.6	S 17.1	N45 34.9	S 50	N135 5.4	T135 11.7	S 7.7	S 16.1	N135 10.8	I 3.8	S 7.9	N45 11.9

GROUP B		B ₁		B ₂		B ₃		B ₄		B ₅		B ₆
GREATEST % INCREASE	LEFT T135 7.1	RIGHT N135 14.8	LEFT T 7.14	RIGHT T45 21.1	LEFT T 12.5	RIGHT N135 22.2	LEFT T 12.5	RIGHT N135 14.3	LEFT T 7.1	RIGHT N135 29.6	LEFT I 19.6	RIGHT N135 33.3
GREATEST % DECREASE	T45 17.4	I 17	S 21.1	T 6.9	S 26.3	T45 28.2	N45 15.9	N45 19	T45 27.7	NIL	N135 8.1	NIL

GROUP C		C ₁		C ₂		C ₃		C ₄
GREATEST % INCREASE	LEFT S 44.4	RIGHT N135 22.6	LEFT N45 50	RIGHT N135 41.4	LEFT N135 41.9	RIGHT N135 23.4	LEFT I 44.4	RIGHT N135 39
GREATEST % DECREASE	NIL	T45 12	NIL	I 10.3	S 9.6	N45 3.8	T45 21.7	I 11.3

GROUP D		D ₁		D ₂
GREATEST % INCREASE	LEFT T 15.3	RIGHT T 4.5	LEFT T135 3.3	RIGHT T135 3.2
GREATEST % DECREASE	N45 7	N 24.4	S 48.5	I 7.3

GROUP E		E ₁		E ₂
GREATEST % INCREASE	LEFT T45 45.2	RIGHT T 9.7	LEFT N135 17.2	RIGHT N135 8.1
GREATEST % DECREASE	N135 10.5	S 28.6	N45 8.9	S 7.5

Fig. 2 Hamblin Perimeter

GROUP F		F ₁		F ₂
	LEFT	RIGHT	LEFT	RIGHT
GREATEST % INCREASE	S 85	T45 50	T45 25.6	T 8.1
GREATEST % DECREASE	NIL	NIL	N45 31.8	N45 28.6

Example: In Test C (smooth tracking of the eye) subject C₂ had the greatest percentage increase of the whole group in the Nasal 45° axis of the left eye (50% above normal). Subject C₄ had the greatest percentage decrease in the temporal 45° axis of the left eye (21.7% below normal).

The initial stimulus for smooth tracking is the image movement over the retina (Walsh, 1957 and Rashbass, 1961), the eye being able to 'follow' providing the speed is no greater than 30 degrees per sec. as measured at the eyeball. Group C show large percentage increases in all but seven axes out of a total thirty-two. It has been found that differences between athletes and non-athletes in peripheral perception has been found to be removed by repeated tests of this nature. The bias would thus seem to lie towards practice in such tests where they are related to relevant individual sports (Johnson, 1952) such as those of the clay pigeon and snap target variety.

Rhodopsin is the visual purple found in the rods of the peripheral retina. By imposing large doses of intense light on the retina, as in group D, it was intended to bleach the photopigment and study the response of the cones which are dominant in the early dark adapted state. The right eye of D₁ shows decreases in all but the temporal axis; the left eye of D₂ reveals a similar response. Despite the fact that both subjects were very skilful sportsmen, D₁ as a first class tennis player and D₂ as an international hockey goalkeeper, each suffered drastic diminution in the axes of at least one eye, D₁ in the right, and D₂ in the left and five axes of the right. It would appear that regardless of skill and possible attendant dynamic visual acuity, one cannot sustain intense flashes of light with impunity. Flashes of less than a millisecond's duration in the excised eyes of albino rabbits have resulted in a bleaching of both rods and cones, which, it has been estimated, takes about 35 minutes for regeneration in the living eye. One can make interesting surmises as to the probable state of the human eye which sustains glare from flash-bulbs, floodlighting and playing into the sun against opponents.

It has been postulated that disorientations in rotary movements of the body, such as in the novitiate stages of learning hammer throwing and tumble turns in swimming, may be related to disordered eye movements which are made in unavailing attempts to focus the eyes upon some fixed point in space (Miller, 1959). On the other hand this phenomenon may be ascribed to

vestibular influences. Certainly the fluctuating peripheral responses of the axes of E₁, a vertigo sufferer, contrast markedly with those of E₂, a very good basketball player and fair exponent of squash, leading to the supposition that E₂ would make more successful attempts at rotary movements in which the peripheral retina partook.

Discussion

Unlike the frog, man is not likely to starve to death surrounded by dead flies because his retinal reflexes have ceased because of lack of stimuli (Burton, 1970), yet the periphery of the retina is a vital part of the complete 'coups d'oeil'. For spatial relationships between different parts of our surroundings may not be clearly conscious to us until something happens to change them in an unusual way. Then our disordered bewilderment indicates how little we have perceived in a retinal sense.

As with any other animal tissue, the retina is able to convert glucose, lactate or pyruvate into carbon dioxide and water aerobically; anaerobically, however, it would cease to function. It is believed to have the highest rate of consumption of oxygen per milligram of dry weight of all the tissues (Papst, 1955). In practical terms this would suggest an avoidance of the 'optical filter' phenomenon in such activities as caving and mountaineering where the peripheral 'early warning system' (Gregory, 1972) is diminished dangerously through a lowering of the basal metabolic rate and that 'Abnormal vision and stumbling' (D.E.S., 1972) of the hypothermia syndrome is approached. Similarly, changes in visual thresholds with a shrinking of peripheral fields owing to the influence of anoxia and alcohol have been noted and are confirmed elsewhere (Muir, 1973). The oxygen capacity of arterial blood can be diminished by an inefficient amount of functioning haemoglobin circulating in arterial blood so the state of the peripheral 'map' may be equally inefficient in the anaemic adolescent as in the 'Extra B Rugby' player who has fortified himself with a few pints before taking the field.

Fig. 3.

CHART B5: NORMAL STATE OF THE SUBJECT'S EYES TAKEN PRETEST. SOLID LINE REPRESENTS RIGHT EYE; DOTTED LINE REPRESENTS LEFT EYE.

F = POINT ON WHICH FOVEA FOCUSES (c.1.3° OF ARC).

S = SUPERIOR AXIS MEASURED FROM CENTRE OF CHART.

I = INFERIOR AXIS.

10-90 = DISTANCE FROM CENTRE OF FOVEA IN DEGREES.

45-90-135 = RADIAL ANGLE AT WHICH READINGS WERE TAKEN.

Fig. 4.

CHART B5: TAKEN AFTER 24 HOUR FAST.

NOTE: DOMINANCE OF PERIPHERY OF RIGHT EYE AND ITS EXPANSION FROM THE NORM.
NOTE ALSO SHRINKAGE OF LEFT EYE.

Fig. 5.

CHART B6: TAKEN 15 MINUTES AFTER END OF FAST AND AFTER INGESTION OF 14 GRAMMES OF GLUCOSE.

NOTE: A MORE BALANCED EFFECT ON THE PERIPHERY OF THE TWO RETINAL FIELDS.

Satiation, as with habituation, would seem to be caused, not by retinal fatigue, but by a process in the central nervous system and may account for the large decreases noted in subject A₂ as well as the glazed look which can be seen among rebellious fifth formers who are made to do an activity they do not relish.

At the extreme edge of the retina, stimulation may not produce perception but it can initiate a reflex which causes the eye to rotate, bringing the moving object into central vision (Poffenberger, 1912). This mechanism has varying degrees of application and can be regarded as a very 'personal *visual* equation' (Cratty, 1967). The full-back at rugby must concentrate on fielding a high kick and inhibit the stimuli of approaching opponents who impinge upon his peripheral field; the climber's

reach may have exceeded his grasp so that he is afraid to turn his head. In each instance the periphery of the eye may, indeed, have 'shouted' its message to the brain but may be told in reply, through any of the inhibitory fibres at the synapses of the neural junctions along the corticogeniculo-retinal tract to 'whisper' its message because of the attention demanded by the other senses. (Tello, 1904). Control has now changed from within-outwards and thus is centrifugal.

The periphery of the retina hence appears to be a device to alert the organism to approaching dangers, a 'span of apprehension' (Vernon, 1971) whose boundaries fluctuate under varying physiological conditions and whose control is under the higher integrative centres of the brain.

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