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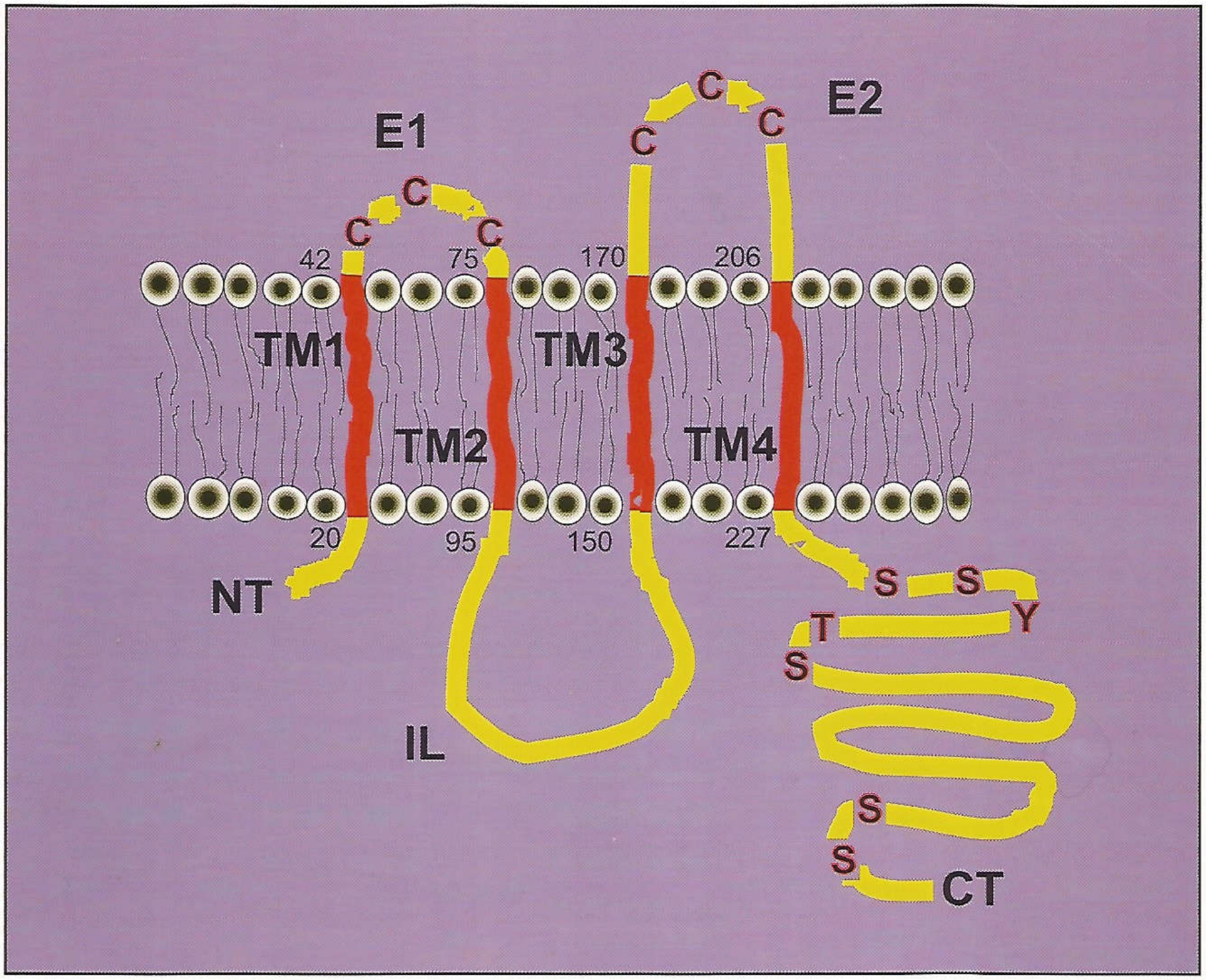

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Using Saccadic Eye Movement Latencies to Measure Retinal Summation Areas

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Abstract

A visual tracking method was used to estimate the size of a possible retinal summation area in humans. Stepping luminous targets were presented to subjects whose eye movements were tracked by an infrared device. The size and intensity of the targets were reciprocally adjusted to give constant luminous power at the eye. At a retinal eccentricity of 5°from the fovea, saccadic latency to relatively intense constant-power targets changed little for targets of up to 0.7-1.25° diameter, leading to the conclusion that the actual summation area, if one exists, might be of that same size.

Introduction

Techniques used by the human retina to process complex visual stimuli are still somewhat mysterious. It has long been suggested that there exist areas of retina over which light inputs are pooled to aid in the detection of dim or poorly contrasted stimuli.

Experiments at the perceptual threshold of night vision have shown that the area over which complete spatial summation of stimulus energy incident on the retina occurs typically extends over no more than 0.4-1° at retinal eccentricities of 5-20° from the fovea (Hallett, 1963, 1991). (See Table 1 for definitions of europhysiological terms.) Within such an area of retina, occulomotor responses should remain constant, as light inputs are pooled to elicit a singular response. The extent of the complete energy summation area for saccadic eye movements remains unknown.

However, a pair of widely separated visual targets can elicit a short latency saccade aimed at some intermediate point, whether the targets are consecutively or simultaneously presented. The question that the following experiment explored was whether a spatial region of complete energy summation could be demonstrated for saccades, with saccadic latency as the testable criterion instead of accuracy of fixation. It was asked over what range of target sizes do constant-power targets elicit a constant latency response.

Through the examination of eye movements, then, an underlying theorectical anatomical structure may be elucidated.The study of saccadic latencies has long been associated with the development of techniques for diagnosing lesions in the human brain. While the purpose of this experiment is considerably more modest, it is recognized that saccadic studies may eventually prove useful in direct medical diagnostics.

In these experiments, a range of target sizes for which target power and saccadic latency are both constant is sought. Employing fairly high power targets finds a roughly 1° area of approximately constant latency, larger than the value that might be expected from perceptual thresholds, but intriguingly similar to the size of the large perceptive fields implied by flicker and motion studies (e.g. Anstis & Harris, 1987).

Methods

The methods and instrumentation described in Perron and Hallett (1995) were used. Circular targets were presented on a uniformly lit high resolution video screen of 11 cd/m^2 background at a viewing distance of 78.5 cm in a dimly lit room. Two types of target were used, ordinary disks and "blobs" of a Gaussian intensity profile (e.g., Bijl, Koenderink and Toet, 1989; Hofmann & Hallett, 1993). Sizes and intensities were adjusted so that corresponding disks ("sharp" targets) and blobs ("blurred" targets) maintained the same luminous power. The sizes and intensities of the targets were further reciprocally adjusted to give constant integrated luminous intensity in candela.

The targets were presented in two polarities or directions relative to the background: incrementally and decrementally, though these types were never mixed in the same trial. By "incremental" is meant a target brighter or whiter than the background, and "decremental" is meant a target darker than the background. Figures 1a and 1b show the intensity profiles of blurred and sharp targets (both incremental) superimposed onto one another to show that the volume of light is kept relatively constant. In these figures, the horizontal axis represents the diamaters of the targets, while the vertical axis represents their brightness.

The decremental targets display the same intensity profiles in the opposite y-axis direction.

A single target was exposed at one of 7 positions in a 2-dimensional array of target positions, and was hidden again simultaneously upon the exposure of the next target. The hidden targets were switched between sharp and blurred or rotated around the screen every 25 trials to provide new tracking sequences, so that the targets appeared to "step" about the 7 possible locations with a 50% probability of being either blurred or sharp. Nine sizes were blocked in each session of 150 target steps each, and at least three sessions were completed by each of four subjects.

Control experiments used a mydriatic drug to fix pupillary diameter, but results are not shown.

Eye movements were measured with the corneal reflection tracker of Frecker, Eizenman and Hallett (1984). The device measured the speed, duration and amplitude of subjects' eye movements by tracking perturbations of infrared light reflected off of subjects' corneas. Trials were accepted if an invisible goal zone, 1° wider than the target, was reached after only one or two saccades. With reasonably accurate tracking, the targets were restricted to the vicinity subtended by 5° retinal eccentricity. Latencies for a trial of saccades to a given target size were pooled to produce an average latency. Pooling of the 150 saccades seems justified, given the reasoning of Perron and Hallett (1995) who maintain that positional aspects of a display have only small effects on saccadic latency, compared to target size, contrast and colour.

Four subjects were instructed to track the stepping targets as quickly and accurately as possible. The results of two subjects, RSD and BGS (the naive control), are shown, and are quite representative of the peformances of all the subjects.

Figure 2 shows all 7 circular targets revealed. Shown in figure 2 are the usually invisible square goal zones surrounding each target, and the infrared detector's plot of the paths of saccades from one goal zone to another.

When reporting and analyzing the results, sharp-edged and blurred targets were compared only after the blurred "blobs" were mathematically converted to diameters of cylinders of equivalent energy. The angular diameters of both sharp and blurred targets are plotted on the same scale. Sizes were 0.36 - 1.82° when sharp and 0.44 - 1.57° when blurred.

Results

Figures 3 and 4 show, for two different subjects,

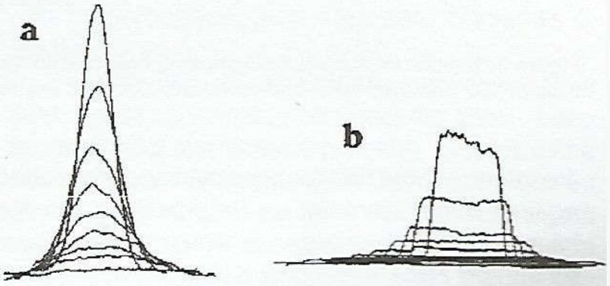

Figure 1, Intensity profiles of incremental targets. Different sizes are superimposed for both (a) blurredtargets and (b) disk targets.blurredtargets and (b) disk targets.

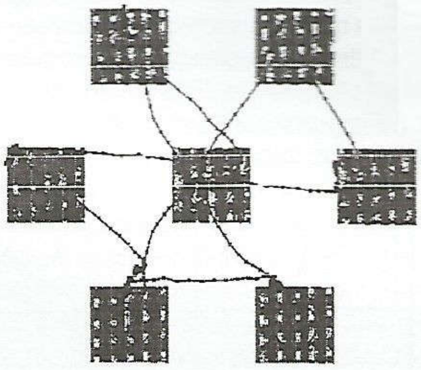

Figure 2, Relative locations of seven targets on video screen, with square goal zones surrounding each target. The dotted lines represent the paths of saccades, with saccadic speed varying with dot separation.

Table 1, Gloassary of topic-specific neurophysiologic terms

Term	Definition
Saccade	A voluntary eye movement.
Saccadic Latency	The time between the presentation of a visual target and the commencement of a saccade toward that target.
Fovea	Portion of the retina with the highest concentration of photoreceptors.
Spatial summation	The phenomenon of light energy being pooled over an area of retina.
Ricco area	Theorized spatial summation area with specific threshold to elicit saccade.
superior colliculus	A portion of the brain involved in occulomotor activity.

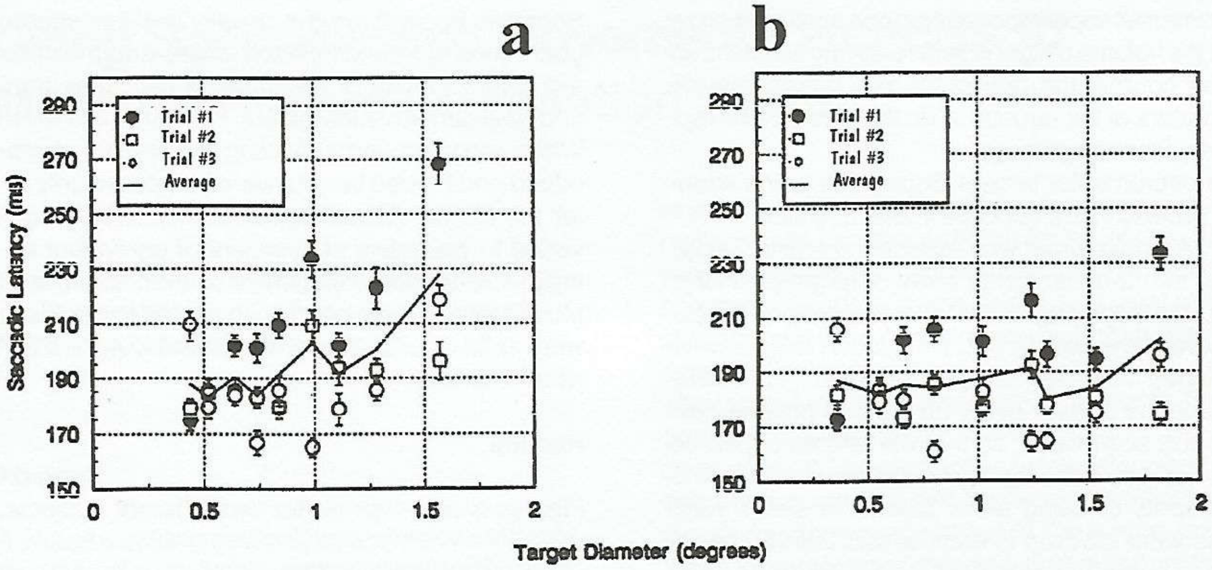

Figure 3, Results for subject RSD showing both blurred targets (a) and disk targets (b). Different symbols show three different trials of 150 averaged saccades each, with a straight line through the mean.

the latency of the first (or primary) saccade plotted against target diameter as the abscissa. In the interests of brevity, only decremental data are shown for subject RSD, while only data from incremental targets are shown for subject BGS. The different symbols in these figures represent the different sessions or trials, with a continuous line through the means. With all subjects and target type, there is noticeable between-subject and between-session variation, with the latencies of the naive subject BGS being particularly stable (Figs. 4a and 4b). The simplest summary of the data as a whole would be that latency remains fairly constant until target size exceeds about 1.25°. More careful examination suggests that the latencies for the sharp-edged targets are nearly constant across most sizes (Figs. 3b and 4b), while latencies for the blurred targets tend to rise earlier at around 0.7 - 1.0° diameter (Figs. 3a and 4a). A statistical ANOVA test revealed that there are no appreciable differences between incremental and decremental targets, p>0.05.

Discussion

A spatial region of constant latency to targets of constant space-integrated power (photons/s at the

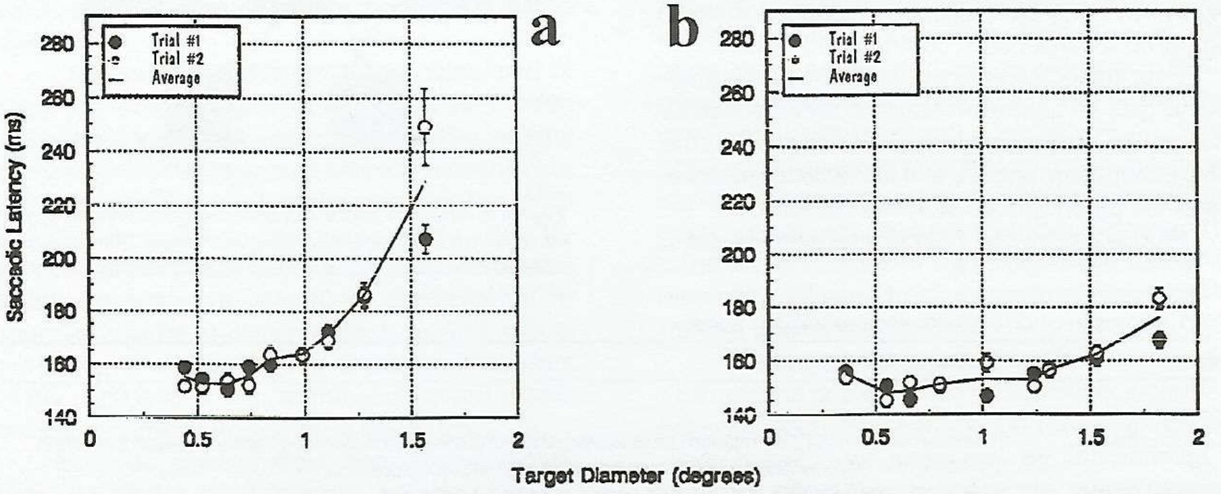

Figure 4, Results for naive subject CSB showing both blurred targets (a) and disk targets (b). Different symbols show three different trials of 150 averaged saccades each, with a straight line through the mean.

pupil or retina) implies, as one possibility, a so-called Ricco area, receptive field centre or point spread function of corresponding extent. Constant power targets up to this critical size would deliver a nearly constant number of photons to the receptive field centre, with the sensory response passing through some threshold trigger value at a fairly well-defined time, so that the overall saccadic latency remains nearly constant. Increasing saccadic latencies with further target expansion would then be due to fewer photons acting on the receptive field centre, and an increasing delay in crossing the threshold. One interpretation might therefore be that there is complete spatial integration of the photon catch from targets of 0.7 to 1.25°, these being small compared to the extent of the implicit spatial filter or receptive field centre.

The experiments found that the spatial extent of the region of roughly constant latency extended to about 1° target diameter for relatively intense targets. Can these findings be reconciled with a wider literature? By and large they can, though some other uncertainties remain. The results are numerically consistent with a variety of studies.

Partial summation up to a limit of about 1.2-1.6° in comparable experiments at the present eccentricity is also one explanation of why saccadic latency falls when constant contrast targets are expanded to this range of sizes (Perron & Hallett, 1995). And in a study of saccadic accuracy, a distractor spot at 3 - 6° retinal eccentricity altered the aim of saccades to targets that were within 0.4 - 1.5°, depending on direction (Deubel & Findlay, 1993).

Anstis and Harris (1987) found a further photopic perceptive field size that would be 1.27° at 5.1° eccentricity, based on the sizes of squares on a persistently fixated, high contrast luminous checkerboard. Similarly, in the "fine grain" motion illusion, successively flashing two very close spots causes an impression of motion over a more extensive region; the extent of the inferred perceptive field was about 1.45° at 5° eccentricity (e.g., Foster, Thorson, McIlwain & Biederman-Thorsen, 1981).

However, spatial summation or integration is only one aspect of receptive field function. Manual reaction times (Wilson, 1984) raise the possibility that expanding a sharp-edged constant intensity target disk might initially reduce saccadic latency and then increase it. The present design with varying intensity is not likely to detect such a relation. More appropriate experiments have shown evidence for an optimal target size in only one of three subjects tested, though this might have been due to target contrast being rather low (Perron & Hallett, 1995).

This study does not exhaust the possible approaches with the present targets, though there are technical limitations to video displays. Ideally, targets of greater power would have been presented in order to see if the region of constant latency continues to expand (and thus falsify the apparent agreement with the estimates from the literature). The targets were not presented as brief flashes of constant energy, though this does not seem very important because exposure time was controlled by requiring a constant latency response.
Furthermore, alternative descriptors of nonlinear systems might have been explored within the context of this study. For example, "signal contrast energy" (the square of contrast) has found some use in perception (e.g.,Tiippana, Nasanen & Rovamo, 1994).

Finally, it is unlikely that any simple receptive field model can explain all saccadic data. Long range spatial interactions probably require some additional mechanism; for example, a few saccades aimed midway between two successive targets appear 40° apart in opposite visual hemifields (Becker & Jurgens, 1979), or between a single target and an instructed goal that are similarly 20° apart (Kalesnykas & Hallett, 1987).

Conclusion

The present experiment on saccadic latencies to constant power sharp and blurred (disk and blob) targets of variable area, the perceptual literature, and some aspects of the retinal anatomic literatures, seem generally consistent with fairly small receptive field centres of about 1° at 5° retinal eccentricity. It would be of interest to know whether the receptive fields of sensory-motor cells in the superior colliculus are of comparable size, and whether the "spatial averaging effect" of the oculomotor literature does require appreciably larger receptive fields.

Acknowledgement

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References

Anstis S, Harris J (1987) Magnification factor for adaptation of a visual transient mechanism. J. Opt. Soc. Am. 4(8):1688-1698.

Becker W, Jurgens R (1979) An analysis of the saccadic system by means of double-step stimuli. Vision Research 19: 967-983.

Bijl P, Koenderink JJ, Toet A (1989) Visibility of blobs with a Gaussian luminance profile. Vision Research 29:447-456.

Deubel H, Findlay JM (1993) The effect of abrupt onsets on saccades to stationary targets. ECEM7, Seventh European Conference on Eye Movements, p.31.

Foster DH, Thorson J, McIlwain JT, Biederman-Thorson M (1981) The fine-grain movement illusion: a perceptual probe of neuronal connectivity in the human visual system. Vision Research 21:1123-1128.

Frecker RC, Eizenman M, Hallett PE (1984) High-precision real-time measurement of eye position using the first Purkinje image. In: Theoretical and applied aspects of eye movement research (Gale AG, Johnson F, eds) pp 13-20. Elsevier, Amsterdam.

Hallett PE (1963) Spatial summation. Vision Research 3:9-24.

Hallett, PE (1971a) Rapid changes and hysteresis in spatial integration for human rod vision. Journal of Physiology 215:433-448.

Hallett PE (1971b) Disturbances of rod threshold forced by briefly expoded luminous lines, edges, disks, and annuli. Journal of Physiology 215:449-476.

Hallett PE (1991) Some limitations to human peripheral vision. In: Vision and Visual Dysfunction, Volume 5 (Kulikowski JJ, Walsh V, Murray IJ, Cronly-Dillon J, eds). Macmillan, London.

Hofmann MI, Barnes CS, Hallett PE (1990) Detection of briefly flashed sine-gratings in dark-adapted vision. Vision Research 30:145-1466.

Hofmann MI, Hallett PE (1993) Texture segregation based on two-dimensional relative phase differences in composite sine-wave grating patterns. Vision Research 33:221-234.

Kalesnykas R, Hallett PE (1987) On plotting amplitude-transition functions for voluntary eye saccades. Vision Research, 27:675-679.

Perron C, Hallett PE (In Press) Saccades to large coloured targets stepping in open fields. Vision Research.

Ransom-Hogg A, Spillmann L (1980) Perceptive field size in fovea and periphery of the light- and dark-adapted retina. Vision Research, 20:221-228.

Tiippana K, Nasanen R, Rovamo, J (1994) Contrast matching of two- dimensional compound gratings. Vision Research, 34:1157-1164.

Wilson A (1984) Reaction time measurement of receptive field properties in the human fovea. Vision Research, 24:289-292.