The Relative Contributions of Rods and Cones in Sensory Memory Under Photopic and Scotopic Conditions

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Brief presentations of letter arrays were probed by bar markers within or outside the fovea after various time delays. Figural information presented to the foveal region was retained better under a photopic condition than information in the parafoveal region, but under a scotopic condition parafoveal information demonstrated superior retention. However, decay rates over time of all functions were similar, demonstrating that figural information in the rods and cones decays at similar rates.

Some evidence has indicated that sensory memory information stored in the cone receptors in relatively ephemeral compared with information stored in the rod receptors. For example, Sakitt and Long (1979), using a successive field paradigm, presented scotopically and photopically matched stimuli and concluded that iconic storage for long interstimulus intervals is mediated by the rods because of the rapid decay of color information within 100 to 200msec. They argued that previous studies demonstrating a superiority in the retention of color information over long interstimulus intervals (ISIs) had failed to match the colors scotopically (Banks & Barber, 1977; Clark, 1969; Coltheart, Lea, & Thompson, 1974; Dick, 1969; Von Wright, 1968, 1970). Consequently, the contrast information still detected by the rods was responsible for these long ISIs. Although Sakitt and Long have demonstrated that color information deteriorates rapidly in color memory, it does not follow that the cone receptors have no role to play when the ISIs are longer. It would be interesting to see how figural information coded within the cones fares.

The relative decay rates of figural information in rods and cones were investigated in the present study. This investigation was done by placement of matrices of letters both in the foveal region and outside it, corresponding to regions of the least and greatest acuity, respectively, for the rod photoreceptors. Only one of these matrices was subsequently partially probed over varying time intervals, revealing the relative decay rates within either the foveal or parafoveal region, depending on which array was probed. Studies demonstrating the superiority of rods have mainly used dark-adapted subjects, but in order to obtain a more complete picture in the present study, subjects were compared under both photopic and scotopic conditions.

METHOD

Subjects and Design

The subjects were five male undergraduates, each of whom experienced all the experimental conditions. Two subjects who were unable to see the stimuli were

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replaced. There were eight sessions for each subject, and within each session there were three blocks of 20 trials with 5-min breaks between each block. Within each block of trials subjects experienced trials randomly testing one of six interstimulus intervals and probing a location on or outside the fovea. The trials were separated by an interval of 20 sec. In half the sessions the subjects were dark-adapted by their wearing goggles with eye patches over both eyes for 40 min before the experiment commenced. Throughout all the experimental conditions subjects wore goggles with an eye patch over the right eye. Thus, in all conditions subjects saw the stimuli with the left eye only.

Materials and Procedure

The successive field paradigm was used ensuring that the probe stimulus in the second field would be processed by the receptors adjacent to the receptors presumably processing the stimuli in the first field. Two projectors with electronically controlled shutters operated by a minicomputer were used to present the two fields. Both fields were shown for 40msec. The intervals of time between the presentation of the fields were 40, 100, 160, 240, 340, and 500msec. In the photopic condition a fluorescent light continuously lit the screen so that the preexposure luminance was 29cd/m. The exposure luminance of each field was 32cd/m. In the scotopic condition the exposure luminance of each field was 3cd/m.

The first stimulus field consisted of two 2×2 matrices of letters, which were presented simultaneously in the foveal and parafoveal regions. The foveal matrix lay within an area of 0.5 to 1 degree in diameter, centered on the fixation point. The other matix was within an area of 4 to 6 degrees from the fixation point. The latter area has maximum acuity for scotopic vision (Mandelbaum & Sloan, 1947; Sloan, 1968). Subjects sat 4m from the screen. The letters in the outer matrix were 7cm in length and those in the inner matrix 1.75cm, and in both matrices they were bold and black. The letters used in the matrices were randomly selected from the alphabet, but certain letters that were judged to be visually difficult (i.e., *Q*, *M*, and *W*) were excluded. Other letters that could be confused with each other, such as *U* and *V*, were not presented together on the same slide. Thus, each slide consisted of two sets of 2×2 matrices of letters, and 32 of these were reused in random order without replacement for each block of 32 trials.

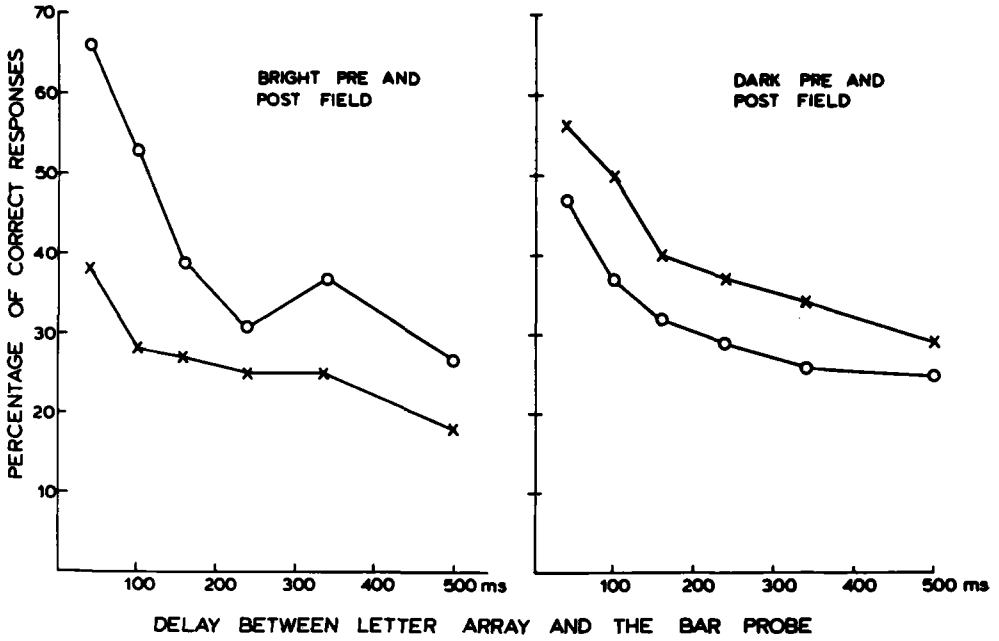
The second field was aligned spatially with the first stimulus and consisted only of the fixation point in exactly the same position and the probe bar. This bar was in a position connecting (without contacting) the locations of what would have been two of the letters within one matrix within the first field. No diagonal connections were used. The task was to name the two letters indicated by the bar. Both letters had to be correctly reported to be counted as correct. When subjects had been dark-adapted, they fixated on a small, dim, red light during each trial. If they reported any eye movements during a trial, it was repeated at the end of the block of trials.

RESULTS

Figure 1 illustrates the decline in performance as a function of the temporal separation of the successive fields. Under photopic conditions, performance on the

FIGURE 1

Percentage of Correct Responses to Stimuli Presented to Areas of Maximum Cone (*O*) or Rod (*X*) Acuity as a Function of the Delay Between the Matrix of Letters and a Bar Probe Under Light- and Dark-Adapted Conditions, Respectively (Each Point Represents the Mean of 100 Trials).



foveal letter matrix was superior to that on the parafoveal matrix. By contrast, under scotopic conditions this situation was reversed and the image of the matrix outside the foveal was retained better than that of the foveal matrix. A $2 \times 2 \times 6$ within-subject analysis of variance on illumination level, retinal location, and interstimulus interval revealed that this interaction between illumination and retinal location was significant ($F = 28.3$; $df = 1,4$; $p < .01$). A significant main effect for time delay was also found ($F = 45.8$; $df = 5,20$; $p < .0001$). One further aspect of the results to note is the relatively sharp decline in sensory memory for the cones under bright conditions until about 200msec, which was mainly responsible for a three-way interaction ($F = 10.5$; $df = 5,20$; $p < .0001$) in the analysis of variance.

DISCUSSION

Our results indicate that both the rods and the cones demonstrate similar types of sensory persistence under both scotopic and photopic conditions. Consequently, in contrast to the view of some previous authors, it is misleading to refer to iconic storage being mediated by either rods or cones. Instead they each have their role to

play in maintaining visual information for a brief period, but their relative efficacy as sensory stores depends on the levels of illumination involved.

The difference between the absolute level of performance of the rods and cones could have been changed within this paradigm by adjusting the ratio of the sizes of the stimuli in and outside the fovea, since the rods have less acuity than the cones (Meyer & Maguire, 1977). In the present experiment a ratio of 1:4 in relative sizes was chosen. Nevertheless, any such adjustment would not have affected the extent of the interaction between retinal location and illumination. For example, if the ratio of fovea to nonfoveal matrix sizes had been adjusted to a level at which rods and cones produced the same level of performance in the photopic situation, this same ratio under scotopic conditions would presumably have produced a more exaggerated difference in performance between the two retinal locations.

In conclusion, we have demonstrated that cones are capable of retaining contrast information almost as well as rods over longer retention intervals. The slight contrast was that there appeared to be a marked decay in information in the cones over the first 200msec. On the evidence of this study and previous studies it is apparent that different aspects of iconic information decay at different rates from the retinal locus. Color information decays quite rapidly from cones, but figural information decays more slowly from both rods and cones.

NOTE

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