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Iconic Storage: The Role of Rods

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Abstract. The hypothesis that rods mediate iconic storage was tested by presenting letters of one color against a field of another. The colors were chosen to be discriminable only by the cones, only by the rods, or both. Under dark adaptation, the rods had little if any effect on partial-report advantage; however, they were important in determining the phenomenal persistence of the stimulus. Under light adaptation, the rods played no apparent role in either type of persistence.

The information in a briefly displayed visual stimulus is not lost as soon as the display ceases. Rather, it persists for a fraction of a second, almost as if the physical stimulus were still present.

This can be shown by the partial-re-

port technique introduced by Sperling (1). An array of letters (say, three rows of four letters each) is briefly displayed and followed by a cue to read the letters in one row. If the cue is delayed by more than a few hundred milliseconds, per-

formance drops to an asymptote, presumably reflecting the limited set of letters that the subject could read and store. But if the cue follows the display immediately, performance is nearly perfect. The subject can direct his attention to the cued row and read the still intact information.

Neisser (2) has termed this brief visual storage the icon. Despite much study, the processes underlying iconic storage remain unknown. We do not even know whether it is of cortical or retinal origin.

A version of the retinal hypothesis has been proposed by Sakitt (3), who has argued that iconic storage can be attributed to lingering signals from the rods. Since rod signals decay with a time constant of about 300 msec (4), this hypothesis has some a priori plausibility, but it still remains to directly test the importance of rods in producing partial-report advantage.

If the icon depends on rod signals, it should be abolished or greatly reduced if the display is of zero contrast for the rods but nonzero contrast for the cones. One way of doing this is to present letters of one color against a field of a different color orange letters against a blue field, for example, with the orange and blue having been selected to stimulate the rods equally. Since the rods are "color blind," they will "see" this display as a uniform field, and so can produce no icon. The cones will see the orange and blue as different.

To present letters of one color and a nonoverlapping field of a different color, a Maxwellian view system was constructed. A stimulus slide was made from a first-surface mirror, etched so that the field region was clear glass, with only the letters remaining mirrored (5). One beam of light, coming from behind the slide, passed through the clear glass everywhere except the letters. The other beam struck the slide from the front and was reflected by the mirrored letters. Thus, the letter and field images were automatically in registration.

Letter arrays were three rows by four columns, each letter subtending 1° of visual angle in height. The entire array was 5.7° wide and 4.6° high. The field was blue (Wratten 44A; dominant wavelength, 492 nm); the letters were orange (Wratten 21; dominant wavelength, 594 nm). The retinal illuminance of the field was 2.2 log scotopic trolands (6). In one condition, the intensity of the orange letters was adjusted so that the letters were clearly discriminable for both the rods and the cones (1.5 log scotopic trolands): in the other condition, the in-

tensity was adjusted so the rods could not distinguish the letters from the field (2.2 log scotopic trolands) (7).

The display was presented to a dark-adapted subject for 50 msec. After a variable delay, an auditory tone (3100, 1350, or 360 Hz) cued the subject to report the top, middle, or bottom row. The four delays (0, 200, 400, and 800 msec) and the two conditions [match (M), non-match (NM)] were presented in blocks of eight trials each, in the following order. Session 1: 0 (M), 0 (NM), 200 (NM), 200 (M), 400 (M), 400 (NM), 800 (NM), and 800 (M); session 2: 800 (M), 800 (NM), 400 (NM), 400 (M), 200 (M), 200 (NM), 0 (NM), and 0 (M).

The partial-report decay curves for the rods alone and for both rods and cones are similar (Fig. 1 A) (8). The rods are not essential, although they may have some role.

The role of the rods can also be examined by finding stimuli that the rods can distinguish while the cones cannot, just as experiment 1 used stimuli that the cones could distinguish while the rods

could not. A color-blind subject, a protanope (9), took part in experiment 2. A protanope cannot distinguish between red and green hues with his cones and can thus adjust the intensity of a red until it looks identical to a green in the rod-free fovea. The red and green that match for the cones look different to the rods, and the red and green that match for the rods look different to the cones. In this experiment, the letters were red-orange (Wratten 24; dominant wavelength, 612 nm) and the field was green (550 nm, provided by a 10-nm half-width interference filter).

The subject first adjusted the intensity of the letters to photopically match the field within the rod-free fovea (10). The field was 1.9 log scotopic trolands, and the letters gave a cone match at 1.2 log scotopic trolands. Thus, for the rods, the letters were 0.7 log unit dimmer than the field. Since only the rods could distinguish the letters, only they could produce an icon.

The subject next increased the intensity of the red-orange letters until

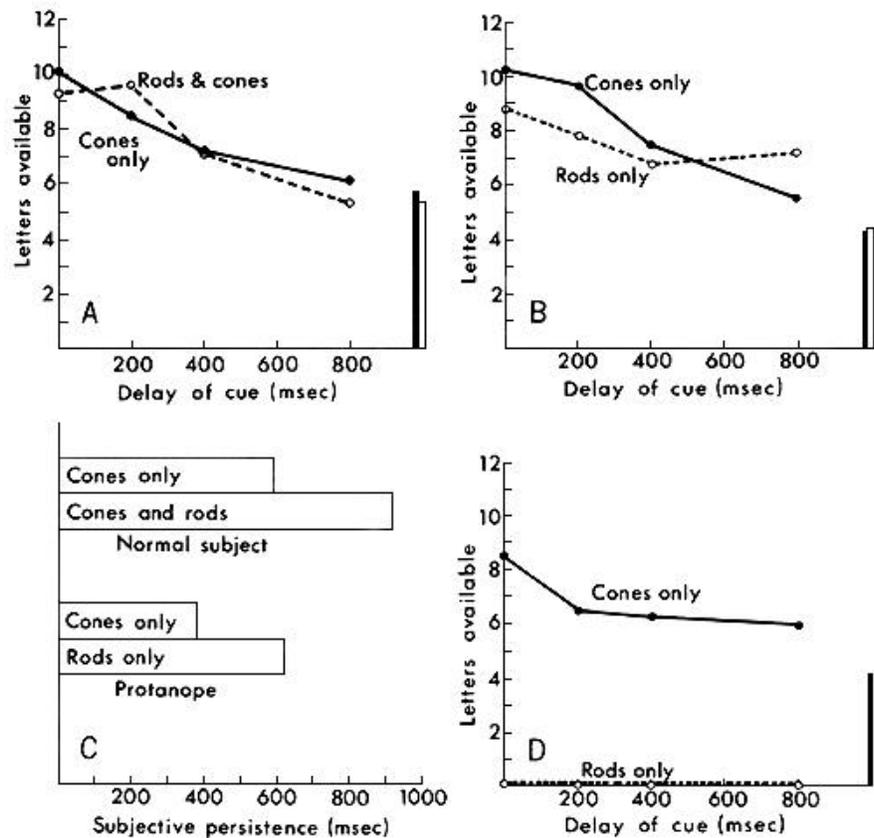


Fig. 1. Visual persistence measured with and without rod participation. (A) Partial-report performance (dark-adapted) for cones with rods and for cones alone. Vertical bars at the right show the whole-report performance. Data are averaged results from two subjects. (B) Partial-report performance (dark-adapted) for a protanope, measured with cones alone or rods alone. (C) Phenomenal persistence (dark-adapted) with and without rod contribution. (D) Light-adapted partial-report performance for a protanope, measured with cones alone and with rods alone. Note points along the abscissa.

they scotopically matched the surrounding green field; thus, both letters and field were 1.9 log scotopic trolands. In this condition only the cones could distinguish the letters, the photopic contrast being 0.7 log unit.

Both the rods-only and the cones-only conditions show fairly standard partial-report effects (Fig. 1B). Under these conditions, either a rod stimulus or a cone stimulus is sufficient to give a partial-report advantage, and neither is necessary by itself.

These findings at first seem to conflict with Sakitt's but in fact they do not. First, she found that, under certain circumstances, a pure rod afterimage was sufficient to produce partial-report advantage. However, there is no reason to believe that a rod afterimage is necessary for this effect. The rods were not necessary under the conditions explored here. Second, she found that rods determined the subjectively judged persistence of a stimulus flashed to a dark-adapted eye, where the persistence was measured by synchronizing an auditory tone with the apparent offset of the image. This is a different task from that used in a partial-report paradigm, and so it might be expected to yield different results.

In fact, it does yield different results (Fig. 1C). With the same stimuli and subjects as before in experiments 1 and 2, subjective persistence was measured according to the auditory synchronization techniques (11). The subjective persistence was dependent on the rods; the image seemed to last between 200 and 400 msec longer with the rods than it did with the cones alone. This corroborates a large body of evidence (12) about the importance of rods in the subjective impressions that follow a flash of light.

Experiments 1 through 3 took place under conditions of dark adaptation. It is worth repeating them with a light-adapted subject. After all, iconic storage was a concept developed to account for ordinary perception, such as that while driving a car or reading a page of text.

The light-adapted protanope repeated the partial-report experiments. The light levels were mesopic (1.9 log scotopic trolands), that is, both rods and cones were participating. A steady adapting field was presented before and after the letter array. In condition 1, the cones could distinguish the letters, but the rods could not; thus, the rods saw a uniform field throughout the experiment. In con-

Table 1. The importance of rods to visual persistence measured by two different tasks and two different lighting conditions.

Task	Lighting condition	
	Dark adaptation	Light adaptation
Subjective persistence	Strong	None
Partial report	Sufficient, but not necessary	None

dition 2, only the rods could distinguish the letters; the cones saw a uniform field throughout.

The cones-only condition shows a brief partial-report advantage (Fig. 1D). In the rods-only condition, there was simply no report at all. Apparently the rods made such a small contribution to the perception that the subject could see no letters. This is not due to rod saturation, since the rods do not saturate below 3 log scotopic trolands.

It is unfortunately difficult to perform the equivalent experiment with a normal subject, because rather special color mixtures are needed to produce "rods only" stimuli. An alternative is to use the Stiles-Crawford effect: to the cones, light entering the pupil through the edge appears dimmer than light entering through the center; to the rods, the lights appear to have the same intensity. By sending the light from the letters and that from the field through different parts of the pupil and adjusting the intensities, the letters were made discriminable to the cones only or to the rods only (13). The results of partial-report experiments, with and without adapting fields were similar to those obtained from the protanope.

Table 1 summarizes the findings by showing the conditions in which rods were important to visual persistence. The only combination of conditions that showed a strong rod role was subjective persistence under dark adaptation. Although the major findings that have pointed to a rod role have been drawn from this quadrant (3), most cognitive psychologists are interested in just the opposite conditions: partial-report effects during light adaptation. These conditions showed no rod involvement.

The term "iconic storage" is sometimes used rather loosely to include a variety of persistence effects, as if there

were only a single process underlying them all. This practice is clearly mistaken; the phenomenal persistence of a stimulus, however, does not necessarily depend on the same processes as the visual storage measured by partial-report advantage.

Since ordinary partial-report effects do not appear attributable to the rods, it would be tempting to conclude that the icon is in the cones such a conclusion is not justified by the results. While the icon might result from persisting cone signals, it might also arise from later processes taking their inputs from the cones.

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References and Notes

1. G. Sperling, *Psychol. Monogr.* **74**, 1 (1960).
2. U. Neisser, *Cognitive Psychology* (Appleton-Century-Crofts, New York 1966) pp. 15-22.
3. B. Sakitt, *Science* **190**, 1318 (1975); *Psychol. Rev.* **83**, 257 (1976).
4. R. D. Penn and W. A. Hagins, *Biophys. J.* **12**, 1073 (1972).
5. The slides were etched as follows. (i) Dry-transfer lettering (Chartpak) was burnished onto the aluminized front surface of a mirror. (ii) The mirror was baked in an oven at 250°F for 3 minutes to assure a good bond with the lettering. (iii) The mirror was dipped in hot sodium hydroxide solution to dissolve the unprotected aluminum. (iv) The transfer lettering was dissolved with methyl ethyl ketone, leaving the mirrored letter beneath it.
6. This corresponds to about 5 mL (15 cd/m²), depending on pupil size.
7. A scotopic match was achieved by the method of F. Flamant and W. S. Stiles [*J. Physiol. (London)* **107**, 187 (1948)], according to which one determines the effectiveness of a background in elevating the rod increment threshold. Two backgrounds that elevate the threshold by 1 log unit are considered to be scotopically equated.
8. W. P. Banks and G. Barber have recently reported a similar result [*Psychol. Rev.* **84**, 536 (1977)].
9. The diagnosis was made with the battery of three spectral tests described by M. Alpern and T. Wake [*J. Physiol. (London)* **226**, 595 (1977)].
10. This protanope found, in accord with V. Smith and J. Pokorny [*J. Opt. Soc. Am.* **67**, 213 (1977)], that the red and green could be made to match only in the fovea. Therefore, all letters except one were masked off, and the match was made foveally.
11. This technique was introduced by G. Sperling [*Acta Psychol.* **27**, 285 (1977)].
12. See, for example, W. S. Duke-Elder, *Textbook of Ophthalmology* (Mosby, St Louis, 1934), vol. 1, p. 955; J. von Kries' appendix to H. von Helmholtz, *Physiological Optics*, J. P. C. Southall, Transl. (Optical Society of America, 1924), vol. 2, pp. 444-448.
13. The difficulty with this method is that the spherical aberration of the eye is large at the edge of the pupil, making it hard to align the letter and field images into perfect registration. Fortunately, it is feasible in my own left eye because my Stiles-Crawford effect is decentered by 1.5 mm; thus neither beam need go through the extreme edge of the pupil.
14. I thank M. Alpern for allowing me access to his equipment, space, and advice. D. Krantz and J. Jonides offered much useful discussion. Funds were provided by EY-00197-20 (to M. Alpern) and by NIMH training grant T32-MH14254.

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