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# Information persistence evaluated with low-density dot patterns

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ABSTRACT

After more than a century of study, we do not yet fully understand how shapes and patterns are encoded and identified. Greater progress might result from quantifying stimulus information, thus allowing manipulation of the degree to which a shape or pattern can elicit recognition. The present work used discrete dot patterns that are seen as letters of the alphabet. By adjusting the density of the dots in each pattern, one can determine the probability that it will be recognized. The experiments displayed low-density dot patterns to human respondents, assessing the interval across which non-redundant information provided by two compatible subsets would combine to elicit recognition. This provided a measure of the time required for decay of information persistence. Viewed in the context of prior work, the evidence indicates that the retina mediates initial visibility of the stimulus trace, but the longer-duration persistence required for memory retrieval is mediated by visual cortex.


## 1. Introduction

One can study the persistence of visual information using letters represented by dot patterns that are displayed with ultra-brief flashes. If one flashes a shape or letter pattern at an intensity that is near the threshold of perceptibility, recognition is nil. But if the pattern is flashed twice at the same intensity with little or no time between the successive displays, the weak influence from each flash will sum, providing a substantial boost to recognition (Greene, 2014; Greene and Visani, 2015). Recognition declines from this high level if one increases the time interval between the two displays, reaching the level that is produced by a single near-threshold display when the temporal separation is approximately 100 ms. One can infer that activation of the visual system that was produced by the first flash grows weaker and essentially disappears across this interval, a process that has been described as visible persistence (Coltheart, 1980; Greene, 2014).

A similar method makes use of two displays that contain partial shape or pattern information that is complementary. Vincent Di Lollo has done extensive work using a task that displays dots that fill the cells of an array, for example a 5 × 5 grid having 25 cells, with one display filling 12 of the cells and second display filling 12 other cells, thus leaving one cell empty. The two arrays are displayed successively, varying the time interval between each. In general the outcome is similar to the intensity summation described above, in that respondents are able to name the empty cell with high reliability when the interval is short and their success declines as the time between successive displays is increased (Hogben and DiLollo, 1974; Di Lollo, 1977; Di Lollo and Wilson, 1978). Here the summation that sustains performance spans 200 ms or more, well beyond the duration of visible persistence. Greene and Visani (2015) have used this approach to study letter recognition based on summation of low density dot patterns and report that the dot-pattern information persists for roughly 200 ms. They argue that the process supporting this persistence differs from that which mediates visible persistence.

The present work examined recognition of small and large letters that were displayed as discrete dot patterns. The first experiments derived "density activation curves" for each letter size, these being regression models that show how the probability of recognition changed as a function of dot density. The second and third experiments used a two-pulse protocol, as outlined above, to determine the interval across which the pattern information would persist. The fourth experiment used a masking protocol to further examine the duration of information persistence.

The mechanisms for preserving stimulus information is discussed, with special attention to the potential role of various brain sites. The evidence generally suggests that visible persistence is mediated by retinal mechanisms and information persistence is mediated by sustained neuron activation in visual cortex.

## 2. Methods

### 2.1. Experimental approval, informed consent, and respondents

The Institutional Review Board at USC approved the experimental protocols. Each respondent signed a consent form that informed him or her of the nature of the experiment and reminded them of their right to discontinue testing at any time and for any reason.

### 2.2. Letter attributes and means of display

An inventory of "thin" Roman (English) letters was used for these experiments, these being generalized using the Hershey Simplex vector

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font criteria. The present construction method used a single-file chain of discrete dots to represent each letter, as illustrated in Fig. 1. Each dot location could be designated for inclusion in a given display, making it possible to modify dot density (spacing) as a treatment manipulation. A given "letter pattern" consisted of the dots that were displayed with simultaneous ultra-brief flashes of light. Details on flash duration and intensity are specified below.

The inventory of letters used in the present experiments included only those letters that could be constructed as a single, continuous chain. This simplified the process for deriving complementary low-density subsets. Observing this restriction, the 15 letters included in the inventory were: C, D, G, I, J, L, M, N, O, P, S, U, V, W, Z.

Each letter pattern was displayed on a 64 × 64 array of light-emitting diodes (LEDs). The display board used AlGaInP LEDs that emit at a peak wavelength of 630 nm, so the light is bright red. Diameters and center-to-center spacing of the LEDs were 5 mm and 9.4 mm, respectively, and the horizontal and vertical spans of the full array were 60 cm. At the observation distance of 3.5 m, the visual angles formed by these spans are 4.92 arc′, 9.23 arc′, and 9.80 arc°.

Two sizes of letters were used in these experiments. Small letters were 20 dots tall (3 arc°) with a maximum width of 14 dots. Mean distance of dots from the center of the letter was 6.95 dots (1.08 arc°). Large letters were 60 dots tall (9 arc°) and had a maximum width of 38 dots. Mean distance of dots from center was 21.25 dots (3.32 arc°).

Although display of a given letter pattern consisted of a simultaneous flash of all the dots comprising a pattern sample, the combined flashes may be described in the singular, i.e., as "a flash". Flash duration for all displays was 10 microseconds (μs), designated as T1. For convenience this interval will most often be described as being "ultra-brief" throughout the report, thought in reporting prior work that term may include other durations in the low microsecond range.

Intensity was measured using a Thorlabs PM100 radiometer with S120C calibrated silicon photodiode sensor. None of the experimental work involved color comparison, so it is appropriate to report the intensity in radiometric units. Further, physiological studies of photoreceptors with monochromatic or LED light sources often report stimulus energy in radiometric units (Schnapf et al., 1990; Packer et al., 1996; Schneeweis and Schnapf, 1999; Field et al., 2009; Cangiano et al., 2012; Cao et al., 2014). With such narrow-range light sources the response of L-cones and M-cones as a function of intensity are very similar (Schnapf et al., 1990).

The amount of steady emission was measured as a function of voltage applied to a given LED. Intensity was scaled as microwatts per solid angle across the range from 0.0001 to 70,000 μW/sr. Then oscilloscope traces from a fast photodiode were captured to verify the timing and relative intensity control of ultra-brief flashes. An Advanced Photonix PDB-C156 PIN silicon photodiode was used in unbiased, unamplified photovoltaic mode, with an appropriate load resistor to convert the current output into voltage, this being measured by a 1 × voltage probe. Flash intensity was verified by comparing oscilloscope traces for flashing and steady emission. Additional radiometer measures were taken with periodic flashes at 500 Hz and higher, well above the meter analog

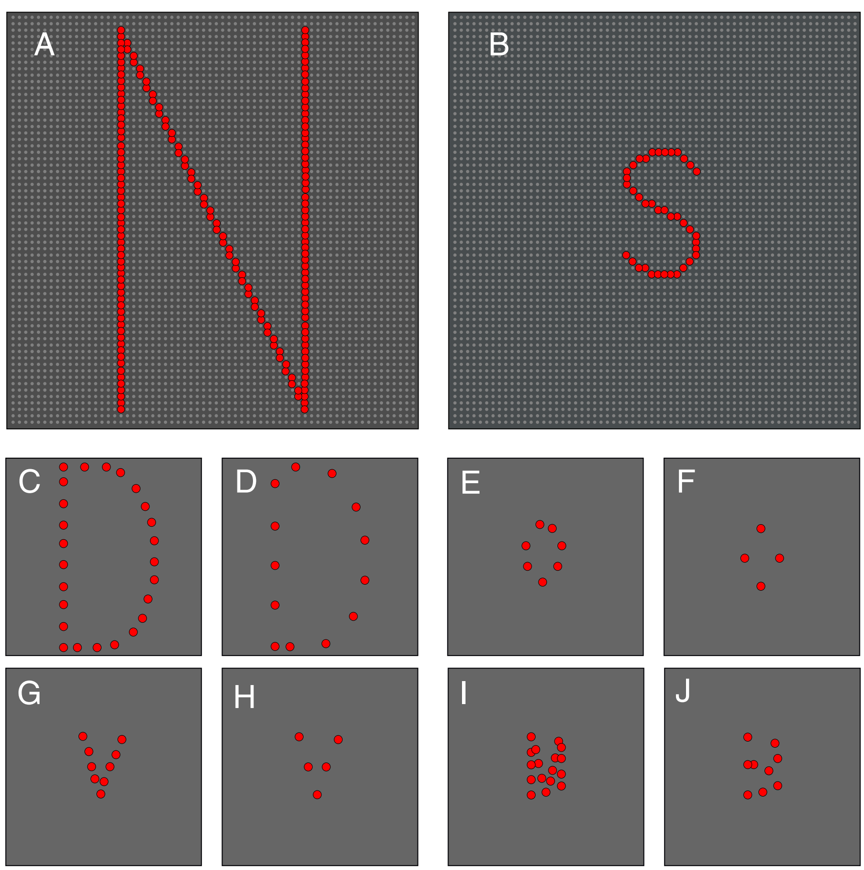


**Fig. 1.** The 64 × 64 array of LEDs is shown in panels A and B, with approximate matching of the relative brightness of unlighted LEDs against the background field. A large letter is displayed in panel A and a small letter in panel B. The static illustration cannot reproduce the salience that flashes generate, so as partial compensation, lighted dots are shown larger than actual LED diameters. This produces an overlap of some dots in the illustration that is not present in the actual stimulus C. A large letter is shown at 15% density, this being the density used in Experiment 2. D. Two 7.5% complementary subsets were derived for display in Experiment 2, one being shown here. The other subset would consist of dots lying between those shown in this panel. E & F: Experiment 2 also displayed small letters at 15% total density, with subsets being at 7.5%. G to J: Experiments 3 and 4 displayed small letters at 22% total density, with subsets being 11%. Dot sizes in C through J are also not to scale. Panel I illustrates that some of the letters were marginally identifiable at 22% density; panels F and J illustrate that many were unlikely to be recognized with densities at or below 11%.