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The effects of memory load and the contrast of the rod signal on partial report superiority in a Sperling task

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Subjects participated in a Sperling task. The independent variables included delay of report cue, dark background field vs. a light background field intense enough to nearly saturate the rod system (duration of rod icon), and whether or not subjects were required to retain a list of letters or words (memory load) while performing in the Sperling task. Partial report superiority is normally taken as an indication of iconic memory. However, the main result was that memory load, which presumably does not affect the duration of the icon, increased partial report superiority. The effect of luminance of the background field was to reduce the partial report superiority. The results show that the existence of a partial report superiority and/or a decaying partial report curve does not necessarily imply the existence of an icon or visual storage.

The existence of a short-term visual storage has been demonstrated in a number of studies, with the earliest ones using partial report sampling techniques (for reviews, see Coltheart, Lea, & Thompson, 1974; Dick, 1974; Sakitt, 1976). Sperling (1960) was careful to state that it is an assumption to state that the visual image, later called icon by Neisser (1967), was the source of the partial report superiority. Unfortunately, the terms icon and iconic memory have been used in the literature in such a way that they refer both to the process responsible for a partial report superiority, and also to the storage contained in the image. One of us (Sakitt, 1976) has already pointed out this difficulty and suggested that "iconic memory" refer only to the storage contained in the icon or image. We employ that terminology here.

In previous studies (Sakitt, 1975, 1976), it was demonstrated that rod photoreceptor activity was the main source of the iconic storage, but it was pointed out "that other factors, including perhaps visual and nonvisual storage as well as output interference, may also contribute to a partial-report superiority. Under conditions in which the icon is weak or masked, these latter factors may play a major role, but under conditions in which there is a robust icon, noniconic storage seems to play a minor role" (1976, p. 274).

The present paper addresses the following question: What are the relative contributions of iconic memory and short-term memory to the partial report superiority in a Sperling experiment?

To study these questions, we used manipulations that would reduce the role of either iconic storage or short-term memory in a Sperling experiment. In order to reduce the role of the iconic storage, we wanted to use a background field upon which the letters were superimposed, since this would reduce the contrast of the icon. It is known that the rod system saturates at roughly 1,000 scotopic trolands (Aguilar & Stiles, 1954), so that at intensities above this critical saturating level, there is no rod icon (Sakitt, Note 1). Therefore, a light background field that is above this critical saturation level will result in only a cone icon that is relatively brief. If the light background is photopic, but well below the rod saturation level, the rod icon will still dominate in iconic storage (Sakitt & Long, in press), although the contrast of the rod icon will be reduced compared to the dark background condition. In the present study, the light background condition was probably close to the level of rod saturation but, for reasons discussed in the next section, it is not clear if the rods were saturated for all subjects. Nevertheless, the rod icon was most probably of very low contrast, and when we use the expression "light background" in this paper, we are referring only to this particular luminance. In fact, for photopic backgrounds that are well below this luminance level, the results are quite different.

In order to reduce the role of short-term memory, we used a large memory load. This was done previously (Chow & Murdock, 1975; Doost & Turvey, 1971), but since we have obtained different results, we will discuss the differences in procedures in a later section of this paper.

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We tested partial and whole reports with and without a memory load and used stimuli presented on no background (dark) or on a bright background field (light). Our conclusions were (1) a partial report superiority does not necessarily imply the existence of iconic memory, and (2) rods probably play the major role in iconic storage under photopic conditions, as long as the rods are not saturated. When they are saturated, iconic storage under photopic conditions is greatly reduced.

METHOD

Apparatus

The experiments used an Iconix three-field tachistoscope. Viewing was monocular with the left eye at a distance of 91 cm. A patch covered the right eye. The light sources in the tachistoscope were 6-W fluorescent bulbs (General Electric, Cool White F615). Two such lamps, operating in parallel, were used to light each field. The exposure time of 50 msec was used in all experiments.

Stimulus Materials

The stimuli were lettered 15 x 23 cm index cards. These consisted of white letters on a black background. The black background was provided by a 14.5 x 16 cm piece of Series 4000 heavy-weight black velour paper (Bienfang Paper Company, Metuchen, New Jersey). A rectangular piece of black velour paper was glued to each index card so that it would cover the part of the card visible in the tachistoscope. The letters were Super Stik vinyl plastic letters, set Number 415, 1-in., Gothic white (E. Z. Letter Quik Stik, Westminster, Maryland). These letters were 2.5 cm high and were affixed to the black velour paper in two five-letter rows that appeared centered in the visual field. The letters in each row were arranged so that their centers were equally spaced. The distance between the rows was 2.5 cm. At the 91-cm viewing distance, the letters were 1.6 deg of visual angle high, the lettered displays were 8.2 deg wide by 4.7 deg high, and the entire exposure field was 8.9 deg wide by 8.0 deg high.

Only the 20 consonants were used to minimize the possibility of subjects' interpreting the arrays as words. For each position, a letter was assigned randomly with replacement and with probability of .05. Two hundred stimuli were constructed in this manner.

There were two types of stimulus conditions, light background and dark background. In the dark background condition, the pre- and postexposure fields were dark, so that the 12.8-ftL white letters fell on retinal regions that were relatively dark adapted. In the light background condition, a constant steady-white background field, formed from another field in the tachistoscope, was displayed. This field, approximately 16.0 ftL, was on continuously before, during, and after the presentation of the white letters. This white background field subtended 8.9 deg wide by 8.0 deg high. In the dark background condition, the fixation spot was a pinpoint of dim red light. In the light background condition, a dark fixation cross was constantly on the light background field.

Light Background Condition Problem

We used a light background condition because we wanted to eliminate or weaken the rod icon and compare whole and partial reports without a rod icon. In order to eliminate the rod icon, one can use a background field that is on continuously (before, during, and after the stimulus) and saturates the rod system. This requires roughly 2.5 to 3.0 log scotopic trolands of retinal illuminance. We turned the tachistoscope luminance to maximum, approximately 16.0 photopic ftL. Making educated guesses about pupil size and the spectral emission properties of the light source and reflecting materials, we estimated the retinal illuminance to be between 2.2 and 2.5 log scotopic trolands. Although this is close to the level that saturates the rods, it was probably just below the critical level. Unfortunately, it was the maximum luminance level obtainable with our tachistoscope. Since photopic backgrounds that do not saturate the rods permit rod icons (Sakitt, Note 1) to be produced, we can only state that the light background condition used in this study reduced the contrast of the rod icon compared to the dark background condition.

Subjects

There were three observers: I.A., M.M., and J.O., all of whom also participated as experimenter for each other. All three had normal uncorrected vision.

Procedure and Instructions

Before each dark background session, subjects dark adapted the left eye by wearing an eye patch for approximately 60 min. These trials were run in a darkened room, except for a partially shielded 12-W lamp that the experimenter used in order to operate the equipment. The lamp was on throughout the session. At the beginning of each session, the subject shifted the eye patch to the right eye so that viewing was monocular to the dark-adapted left eye. In the light background condition, the only differences were that the room lights were left on, and the subjects did not dark adapt before the experiment. However, viewing was monocular in this condition also.

There were two types of trials based on the type of report the subject was required to make. On partial report trials, subjects were told that a tone would be sounded, that this tone would come on either at stimulus exposure or at varying delay after the exposure, and that it would be a high (1,900-Hz) or low (400-Hz) tone. If it was a high tone, the subject was to write down only the upper row of the stimulus; if it was a low tone, the subject was to write down only the lower row.

The rows were cued randomly with replacement so that on each trial there was a .50 probability that a particular row would be cued. Hence, there could be no advantage in cue anticipation. On whole report trials, subjects were instructed to write down all the letters in the stimulus after they heard a tone (700 Hz) at one of the delays. All letters were to be reported in their correct positions. The indicator tone was presented at the following four times after onset of the stimulus: 0, 500, 2,000, and 5,000 msec.

The procedure used was similar to that of Sakitt (1976). The subject held the trial-initiation button in one hand and a pencil, poised above a small writing pad, in the other. Subjects recorded letters without looking at the pad in both dark and light background conditions. This procedure prevented light adaptation of the subject during dark-adaptation conditions. With only minimal practice, subjects could easily record the letters in their proper positions, leaving dashes for letters that could not be recalled. Each page of the pad was used to record the response to one and only one trial. On each trial, the experimenter signaled "ready," then the subject pressed the button that initiated presentation of the stimulus after a 10-msec delay. After recording the response, the subject turned the page and got ready for the next stimulus. Subjects were encouraged to write down as many letters as they could without wild guessing.

There were two types of trials, based on whether the subject had a subsidiary (memory-load) task. The "no-load" procedure has been described. For "load" trials, the experimenter signaled "ready" and, 1 sec later, read a list of consonants or words at a rate of 1 item/sec. The subject then pressed the button initiating presentation of the stimulus and wrote down the letters from the display. Then the subject recalled the load list aloud in any order. The experimenter recorded the subject's responses.

Each session contained eight blocks. The blocks represented a factorial combination of partial vs. whole report, load vs. no load, and two of the four tone delays. Thus all the trials in a block were either partial report or whole report, had either a load or no load, and contained tone cues at only one delay. For each session, two of the four tone delays were chosen at random with the constraint that all conditions be tested equally at all delays over the entire set of sessions. For each block, the subject received 12 trials, 2 practice trials followed by 10 experimental trials. Thus there were 96 trials per session, 16 practice and 80 experimental trials. Within each session, block order was determined randomly. Each session lasted approximately 1 h. Each session was either a light background or a dark background condition. This was necessary in order to prevent light adaptation from the light background from interfering with the dark background condition.

The data for this experiment were gathered at different times for different subjects as the subjects were available. Data collection for J.O. and I.A. each took place over 5 weeks, whereas the data collection for M.M. took place over a 3-week period. Overall, the experiments were run during a 5-month period. Load conditions differed across subjects because we were searching for conditions that would best interfere with partial and whole reports. J.O. received a load of five nouns. M.M. received a load of 10 consonants. I.A. received a load of 13 consonants that was later increased to 17 consonants because he could recall all 13, although the memory load within each session was always constant.

J.O. and I.A. served in 12 sessions in the light background condition and M.M. served in 6. I.A. and M.M. served in six sessions in the dark background sessions first. I.A. and M.M. served in dark and light background conditions in a nonsystematic order based on convenience, since dark background took longer than light background conditions, 1 h for dark adaptation and 1 h for the trials.

RESULTS

The individual data are given in Table 1 and the figures show the mean data for the three subjects. Figure 1 shows the results for the no-load condition for both the dark and light background conditions. The mean data are plotted as letters available vs. stimulus onset asynchrony (SOA). The partial report score is computed by doubling the mean number of letters recalled in the partial report condition, since the stimulus contains two rows of letters. The bars on the right indicate the mean whole reports for the dark and light background conditions (no load) and were relatively constant across SOA, as seen in Table 1.

The main results were (1) the light background reduced both the whole report and the partial report at every SOA, and (2) the light background condition produced a rapidly decaying function, whereas the dark background condition produced a slowly decaying function. These data are consistent with those of Averbach and Sperling (1961), who used light and dark pre- and postexposure fields and obtained somewhat similar results. The data are also what would be expected from most visual phenomena, since the light background field reduces the contrast of the stimuli.

Table 1
Letters Available as a Function of SOA (in Seconds)

	Dark Background				Light Background			
	No Load		Load		No Load		Load	
SOA	P	W	P	W	P	W	P	W
				Subject I.A.				
0	9.9	8.4	9.3	7.4	9.5	6.2	8.2	5.7
.5	9.7	8.4	9.2	7.2	7.3	6.2	7.7	5.7
2.0	9.1	8.8	7.1	5.6	6.6	6.1	5.8	4.8
5.0	8.9	8.4	5.5	4.5	7.2	6.4	5.0	4.4
Mean		8.5		6.2		6.2		5.2
				Subject J.O.				
0	9.7	7.0	9.2	6.3	9.0	6.0	8.0	5.2
.5	9.5	6.7	9.0	5.6	7.5	6.0	7.3	5.1
2.0	8.1	7.0	6.1	4.5	6.2	6.2	6.1	5.1
5.0	7.2	6.7	4.6	4.1	6.4	5.9	4.7	4.5
Mean		6.9		5.1		6.0		5.0
				Subject M.M.				
0	9.5	5.7	8.9	5.3	8.6	5.1	6.5	3.8
.5	8.7	5.8	7.1	4.1	5.1	4.9	6.0	4.2
2.0	6.9	5.4	5.3	4.0	5.4	5.0	3.8	3.5
5.0	5.7	5.7	3.9	3.2	4.9	5.4	2.7	2.9
Mean		5.7		4.4		5.1		3.6

Note—P = partial report; W = whole report.

Figure 2 plots the partial report in letters available vs. SOA for the load condition for both the light and dark background. The bars on the right indicate the whole reports at 5 sec. The light background still reduced the partial report for all SOAs. But the main effect of the load was seen in its effect on the light background condition. Let us define the half-life, T, of the decay curve as the time for which partial report is one-half that at zero SOA. Without a load, the half-life for the light background condition was only .30 sec, as seen by the rapidly decaying curve in Figure 1. However, the effect of the load was to dramatically

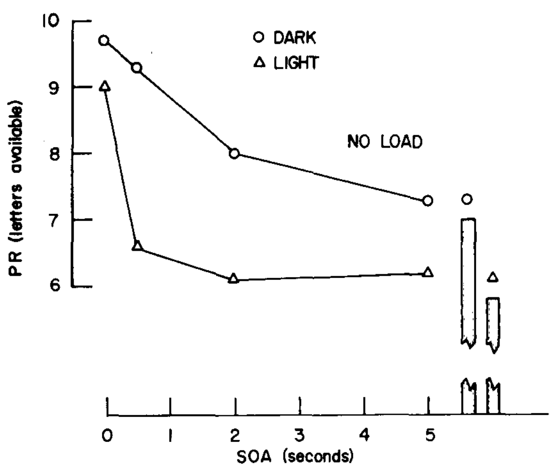

Figure 1. Number of letters available in partial report plotted against SOA for the no-load condition for both dark and light backgrounds. Whole reports, no load, are shown in bars (combined data, n = 3).

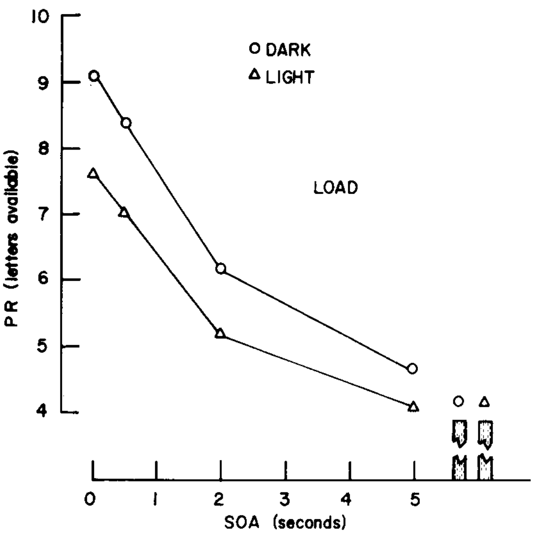

Figure 2. Number of letters available in the partial report plotted against SOA for load condition for both dark and light backgrounds. Whole reports, no load, are shown in bars (combined data, n = 3).

increase the half-life to 1.20 sec (t = 21.3, $p < .005$). It is highly unlikely that the load increased iconic memory, and hence, the increased decay constant of the curve does not necessarily prove anything about a visual memory. The effect of the load on the dark background condition was in the opposite direction, decreasing the half-life from 1.69 to 1.29 sec (t = 3.7, $p < .05$). It is as if the heavy loads we used dominated all reports so that both curves look alike. Also note that the load decreased the absolute performance, both in partial and in whole reports.

The load also had an effect on whole report, as shown in Figure 3, where whole report (letters reported) in the load conditions is plotted against SOA. The bars on the right give the mean whole reports in the no-load

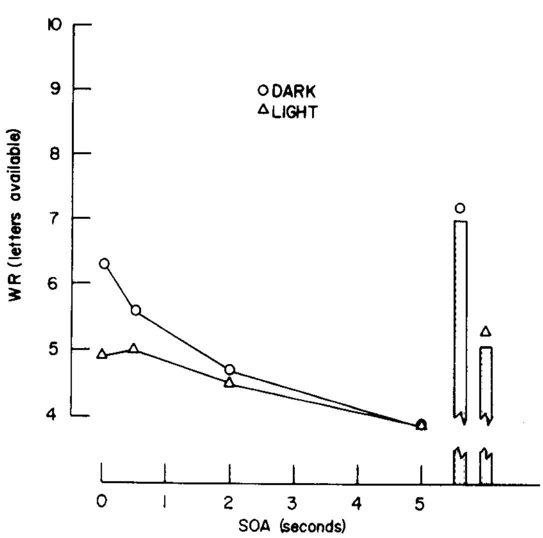

Figure 3. Number of letters available in whole report, load condition for both dark and light backgrounds. Whole reports, no load, are shown in bars (combined data, n = 3).

condition (as seen in Table 1, it was fairly constant, so there was no need to plot it vs. SOA). We calculated partial report superiority using the partial report and whole report at each SOA. For the dark background condition, the memory load increased the partial report superiority for every SOA. The main effect of the load on partial report superiority was significant [$t(2) = 6.98$, $p < .01$]. For the light background condition, the memory load increased the average across-SOAs partial report superiority. The main effect of the load on partial report superiority was significant [$t(2) = 8.2$, $p < .01$].

We note here that although memory loads increased the partial report superiority, they actually decreased both the whole and partial reports. However, they decreased the whole report more than the partial report, which results in an increased partial report superiority. This is obviously not a visual phenomenon, so this proves that a partial report superiority can be induced or increased by nonvisual means.

If the decay of the partial report curve is taken as a measure of the duration of iconic memory, then one could conclude that the memory loads substantially increased iconic memory. Since this is presumably false, it must mean that *the existence of a partial report superiority and/or a decaying partial report curve does not necessarily imply the existence of an icon or visual storage.*

DISCUSSION

Without a load, we found that the light background reduced whole and partial reports and the half-life, T, of the decaying partial report curve. Since the light background was close to, but probably somewhat below, rod saturation, we would expect the rod icon to be of low contrast and the shorter cone icon to be unable to provide much information at long SOAs. This is consistent with other findings. Averbach and Sperling (1961) were the first to show that using pre- and post-exposure light background fields reduced the time over which there was a partial report superiority. It is also consistent with Sakitt (Note 1), who found that rod saturation eliminated long-lasting subjective icons, whereas photopic luminances below rod saturation did not. In other data obtained in pilot studies, we found that with a photopic background less intense than the one shown here, there were large partial report superiorities. However, for the experimental conditions, we used as intense a background as possible, trying to get close to rod saturation. In the no-load condition, the light background produced a rapidly decaying curve as opposed to the dark background, consistent with, but not proving that the icon was less robust.

The effect of the load was to increase partial report superiority and change the shape of the partial report decay curves. This was most dramatically shown in the light background condition. Without a load, the curve decayed rapidly, whereas the load produced a long decay. We note that our results are not in agreement with those of Chow and Murdock (1975) or those of Doost and Turvey (1971). We also note that their results are not in agreement with each other.

But the procedures used in all three studies were different, and this is critical. Doost and Turvey (1971) used a visual load of only one trigram, and there was a variable delay (like ours) between load and Sperling task. Chow and Murdock (1975) also used trigrams, but their study differed from that of Doost and Turvey mainly by "controlling the timing between the short-term memory and the iconic-memory task." Whereas Doost and Turvey found that the load had no effect, Chow and Murdock found that the load reduced the partial report at all interstimulus intervals, but that the shape of the partial report was not affected by the load. This is in contrast to our finding that memory loads reduced the partial report and the shape of the decay curve. Although there were several differences in our procedures, it seems to us that the overwhelmingly important differences were the size of the memory load and the level at which subjects reported. A trigram is a very light load, whereas we used either five nouns or 10-17 consonants, loads heavy enough to tax the capacity of short-term memory. Our subjects' whole reports in the no-load condition averaged 5.1 and 5.7 letters, depending upon background, whereas in the Chow and Murdock study it was 3.0 to 4.0. Also, just looking at percentage correct in the no-load condition at zero delay, our results were 86%-99%, whereas the Chow and Murdock results were only 33%-50%, a very low performance rate. We suspect that the effects of load show up most when short-term memory is most overloaded. To do this requires both heavy memory loads and high performance on the partial report.

We found that the effect of the memory load was to *decrease* both partial and whole reports. The load also *increased* the partial report superiority, because the whole report suffered proportionately more than the partial report. This effect seems to be due to nonvisual interference, and the interference seems to be worse when the total number of items to be retained is increased. That is, whole reports had more items to be reported, so they suffered more on the average. Anderson (1960) has shown that with an auditory list of items, subjects report a smaller percentage of items when asked for the entire list than when asked for just some fraction of it. This is a partial report superiority for spoken items, usually attributed to output interference. However, we do not know the detailed basis for the induced partial report superiority shown here and prefer to describe it in a neutral way as nonvisual interference.

Our results make it clear that both visual and nonvisual factors can contribute to the partial report superiority, but we do not know how to separate these factors within this paradigm. There are some visual manipulations that have a profound effect on the partial and whole reports, such as saturating the rods. But, since nonvisual factors also can affect partial report superiority, we suggest that partial report superiorities be used as being consistent with the presence of an icon, but not as a definite indicator of the presence of an icon.

However, we do not think the results in the present paper threaten the hypothesis of an iconic memory. In particular, the existence of iconic memory for form can also be demonstrated with the successive-field paradigm (Eriksen & Collins, 1967, 1968; Sakitt & Long, 1978) and by the subjective persistence of the icon (Sperling, 1967; Sakitt, 1975, 1976). But we do think that in general, if iconic memory for anything other than form exists, it would be necessary to demonstrate more than just a partial report superiority. We also urge that the absolute values of partial and whole reports receive more consideration than they have previously, since as shown here, partial report advantage and the decay of the curve may not be related to visual memories.

REFERENCE NOTE

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