Journal of Experimental Psychology:
Human Perception and Performance

VOL. 10, NO. 3 JUNE 1984

Measuring Efficiency of Selection From Briefly Exposed Visual Displays: A Model for Partial Report

Claus Bundesen, Leif Flemming Pedersen, and Axel Larsen
Copenhagen University, Copenhagen, Denmark

In the proposed model for partial report, performance reflects the number of targets in a short-term memory buffer. The total number of items (targets, distractors, or extraneous noise) entering the buffer is independent of the number of targets and distractors in the stimulus. Entrance is determined by selective sampling according to a Luce (1959) ratio rule. The model was tested in a variety of conditions with partial reports based on brightness, color, shape, or alphanumeric class. With three parameters, the model accounted for 99% of the variance with number of targets and number of distractors in data obtained by averaging across conditions. Parameter K (number of items entering the buffer) showed little variation with the selection criterion, and estimates for parameter ϵ (total impact of extraneous noise with impact per target as the unit) were rather small. Estimates for parameter α (impact per distractor with impact per target as the unit) varied widely across conditions. Parameter α is a measure for the efficiency of selecting targets rather than distractors.

When trying to report as many items as possible from a briefly exposed visual display of letters or digits, observers average slightly over four items correct (*whole report limitation*). However, when required to report only a subset of the items, such as one out of three rows of letters, the number of correctly reported items may approach the same value, yielding a higher probability correct (*partial report superiority;* Sperling, 1960).

The whole report limitation is rather robust. Sperling (1960) found little effect of variations in number and spatial arrangement of stimulus items and little effect of variation in exposure duration from 15 to 500 ms with dark pre- and postexposure fields (see also Schumann, 1904). If an appropriate mask is presented at display offset, the number of items reported increases rapidly from zero to about four as display duration is increased from zero up to some value between 50 and 100 ms; with further increase in display duration, the rate of increase in number of items reported is much smaller (see Coltheart, 1972, 1980; Sperling, 1963, 1967). To accommodate these findings, Sperling (1967) suggested that the whole report limitation reflects the limited capacity of a recognition memory-buffer with fast read-in and slow read-out.

Partial report superiority has been obtained with a variety of selection criteria (i.e., criteria defining the subset of items to be reported) in both pre- and poststimulus cueing conditions (for reviews, see Coltheart, 1980; Neisser, 1967). The effect depends upon the selection criterion, and the magnitude of the effect—usually measured as the difference in probability correct between partial and whole reports, multiplied by the number of items in the stimulus—has been used as a measure for

The authors wish to thank Jørgen Døssing and Jørgen Rathje for programming and engineering assistance.

Requests for reprints should be sent to Claus Bundesen, Psychological Laboratory, Copenhagen University, Njalsgade 90, DK-2300 Copenhagen S., Denmark.

the efficiency of the selection process (cf. von Wright, 1968, 1970, 1972). Unfortunately, partial report superiority is a crude measure of selective efficiency. As illustrated in the experiments to be reported, the effect is strongly dependent upon the number of targets (items in the relevant subset) and distractors (irrelevant items) in the stimulus.

In this article, we describe and test a model relating performance in the partial report paradigm to the number of targets (T) and distractors (D) in the stimulus display. The model provides a measure for efficiency of selection that is independent of T and D.

Model

The model assumes that both partial and whole report performance reflects the number of targets in a short-term memory buffer with limited capacity, similar to the recognition memory-buffer proposed by Sperling (1967). The total number of items (targets, distractors, or extraneous noise) entering the buffer, K, is independent of the number of targets and distractors in the stimulus.

Read-in to the buffer is conceived as selective sampling without replacement. Selection among items occurs in accordance with a constant ratio rule (Clarke, 1957; Luce, 1959; Luce, Bush, & Galanter, 1963). Specifically, for a given selection criterion, there is a ratio scale v, such that the probability that item i is the kth ($1 \le k \le K$) to be selected equals

$$\frac{\delta(i, k)v(i)}{\sum_j \delta(j, k)v(j)}, \quad (1)$$

where the summation extends over all items; $\delta(j, k) = 0$, if item j is among the first ($k - 1$) items selected; otherwise, $\delta(j, k) = 1$. It is thus assumed that, once an item gets selected, it ceases to affect the selection process.

Three-Parameter Version

If selection among targets is random, $v(i) = v(j)$ for any targets i and j. Similarly, if selection among distractors is random, $v(i) = v(j)$ for any distractors i and j. If both conditions are met, there is no loss in generality by setting $v(i)$ equal to one, if i is a target, and $v(i)$ equal to α, where α is a constant, if i is a distractor.

In some applications, it seems realistic to assume that there is a huge set of extraneous noise items (in the experimental situation or in long-term memory), each having a small probability of entering the short-term memory buffer on a given trial. When K is small, then, the sum of $\delta(i, k)v(i)$ over the set of extraneous noise items changes little as k increases from one to K. Accordingly, the impact of extraneous noise items can be summarized by a single parameter ϵ representing the sum of their v values.

The above simplifications leave three parameters: the number of items entering the memory buffer, K; the impact of a distractor, α; and the total impact of extraneous noise items, ϵ. Parameter α is the proposed measure for the efficiency of selecting targets rather than distractors. If α is zero, selection is perfect. If α equals one, sampling is "nonselective" (Averbach & Coriell, 1961).

To see how the three-parameter model works, consider a subject trying to select as many targets as possible from a briefly exposed display containing T targets and D distractors. Let K equal four. Regardless of T and D, a total of four items is transferred to the short-term memory buffer. If both T and D are greater than one, the probability that the first item selected is a target, the second a distractor, the third an extraneous noise item, and the fourth a target is given by the product of $T/[T + \alpha D + \epsilon]$, $\alpha D/[(T - 1) + \alpha D + \epsilon]$, $\epsilon/[(T - 1) + \alpha(D - 1) + \epsilon]$, and $(T - 1)/[(T - 1) + \alpha(D - 1) + \epsilon]$. If there are two targets in the memory buffer, the simple expectation is that two targets are correctly reported.

An instructive approximation is available when T and D are large in relation to K. In this case, the effect of sampling without replacement is nearly the same as the effect of sampling with replacement. Accordingly, the distribution of the number of targets sampled on a trial is approximately binomial with expectation $\mu = KT/(T + \alpha D + \epsilon)$, so the reciprocal of the expected score is given by

$$\mu^{-1} = (\alpha/K)(D/T) + (\epsilon/K)(1/T) + (1/K). \quad (2)$$

Plotting μ^{-1} as a function of (D/T) with T as a parameter should thus produce a set of straight lines with a common slope of (α/K). Moreover, when appropriately averaged, group data should show the same pattern as individual data. If Equation 2 applies to each of n sets of expected scores, say, values of μ_i expected with parameter values K_i, α_i, and ϵ_i, for $i = 1, \ldots, n$, it follows that

$$\text{Av}[\mu_i^{-1}] = \text{Av}[\alpha_i/K_i](D/T) + \text{Av}[\epsilon_i/K_i](1/T) + \text{Av}[1/K_i], \quad (3)$$

where "Av" is an abbreviation for "$(1/n) \times \sum_{i=1}^{n}$" (arithmetic mean). Therefore, plotting μ_h^{-1}, where $\mu_h = 1/(\text{Av}[\mu_i^{-1}])$ (harmonic mean), as a function of (D/T) with T as a parameter should again produce a set of parallel lines, the common slope being equal to $\text{Av}[\alpha_i/K_i]$.

The three-parameter model for partial report was tested in Experiments 1 and 2.

Experiment 1

Method

Partial reports were based on color (color condition) or alphanumeric class (alphanumeric condition). In either condition, number of targets and number of distractors were varied, and the number of targets correctly reported was recorded. The spatial distribution of the items was random and varied from trial to trial.

Subjects. Four male subjects with normal or corrected-to-normal visual acuity and normal color vision were recruited. The subjects were students or members of the staff at Copenhagen University, between 25 and 35 years old.

Displays. The stimulus material for the color condition comprised 180 slides each of which displayed a number of capital letters positioned within an imaginary 5 × 5 matrix. The slides were photographed from computer-generated displays written by an electric typewriter in elite typeface. Under the experimental viewing conditions, a single character subtended approximately .89° in width and 1.00° in height. Center-to-center distance between adjacent characters in the same row of the 5 × 5 matrix was 2.15°. Center-to-center distance between adjacent characters in the same column was 1.78°. The characters were either black or red (with an approximate Munsell notation of 7.5YR 6/10), and the background was yellowish white (2.5GY 8.5/4).

Let m be the number of red letters in a display and n the number of black letters. Possible values of m and n were 0, 5, 10, 15, and 20. Factors m and n were varied orthogonally with the constraint that $0 < (m + n) \leq 25$, which gave a total of 18 possible combinations of m and n. Each of the 18 combinations was represented by 10 different displays. In each display, the spatial distribution of the $(m + n)$ items over the 5 × 5 matrix was random. Identity of individual items was determined by drawing at random, with replacement, from a set of 21 consonants (Y included).

The stimulus material for the alphanumeric condition conformed to the same specifications as the material for the color condition with black digits substituted for red letters. Identity of individual digits was determined by drawing at random, with replacement, from a set of nine digits (*0* excluded).

Tasks. In the color condition, the target set was either the red items or the black items; in the alphanumeric condition, it was either the letters or the digits. The subject was to report all those targets, and only those targets, of which he was "fairly certain" that they were correctly identified; he was to indicate the locations of these targets as accurately as possible, guessing if necessary.

Procedure. The subject was seated in a semidarkened room about 2 m in front of a screen on which the projections of the slides subtended approximately 12° of visual angle horizontally and 10° vertically. A full 5 × 5 stimulus matrix subtended 9.5° in width and 8.1° in height. The display was viewed binocularly with free fixation. During projection of a slide, the pupils of the subject received an illuminance of about 1.6 lx from the stimulus field (i.e., the projected slide) and 0.3 lx from the surrounding field.

Each trial was initiated by the subject. When he pressed a key, the stimulus display was immediately exposed for a period of 60 ms. The subject wrote his report on a response sheet by filling in a number of cells in a printed rectangular grid five cells wide by five cells high representing the stimulus matrix.

Scoring. Displacements of one cell between stimulus and response characters were tolerated. Any response character was thus compared with all targets in locations that were displaced at most one cell (horizontally, vertically, or diagonally) from the response location, and responses were paired with targets such that the score (number of correctly reported items) became as high as possible.

Design. The subjects served individually in two experimental sessions. Each session comprised four blocks of 180 experimental trials: one block with report of red items in the color condition displays; a second block with report of black items in the color displays; third, report of letters in the alphanumeric condition displays; fourth, report of digits in the alphanumeric displays. Order of blocks was counterbalanced over subjects and sessions. Ordering of trials within blocks was random.

Every block was preceded by about 25 trials for warming up. The first experimental session was preceded by a practice session comprising about 200 trials in which similar stimulus material was employed to familiarize the subject with the procedure.

Results

Color condition. The group mean score (number of correctly reported items) in the color condition is shown in Table 1 as a function of target color, number of targets (T), and number of distractors (D). Scores were slightly higher for black than for red targets, but effects of T and D were similar for the two target colors: With a few, local inversions, the mean score was an increasing function of T (with D kept constant) and a decreasing function of D (with T kept constant). The product-moment correlation between the mean score and the mean number of erroneously reported items as functions of T and D (see Table 1) was negligible, $r = -.03$.

Averaged across target colors, probability correct (mean score divided by T) varied between .712 (for $T = 5$, $D = 0$) and .188 (for $T = 20$, $D = 5$). It decreased systematically with both T and D. Partial report superiority obtained with a given combination of T and D (such that $T, D > 0$ and $T + D < 25$) was computed by multiplying probability correct for this combination with the total number of items in the stimulus and subtracting the mean score obtained with displays containing the same number of items but no distractors. It increased with D and decreased with T. Considering displays with $(T + D) = 20$, partial report superiority was 1.08 items for $T = 15$, 2.96 items for $T = 10$, and 7.99 items for $T = 5$.

Table 1
Numbers of Correctly and Erroneously Reported Items as Functions of Target Type (Red vs. Black), Number of Targets, and Number of Distractors in Color Condition of Experiment 1

Number of targets	Number of distractors: 0	5	10	15	20
	Correct with red targets				
5	3.49	3.05	2.80	2.89	2.36
10	3.54	3.38	3.39	3.28	
15	3.90	3.59	3.36		
20	3.81	3.84			
	Correct with black targets				
5	3.63	3.39	3.06	3.04	3.08
10	3.69	3.45	3.44	3.45	
15	4.04	3.83	3.48		
20	3.93	3.69			
	Errors with red targets				
5	1.00	1.21	1.23	1.00	1.52
10	1.09	1.21	1.10	1.12	
15	1.18	1.24	1.44		
20	1.29	1.21			
	Errors with black targets				
5	0.88	0.99	1.27	1.29	1.23
10	1.16	1.40	1.31	1.34	
15	1.17	1.26	1.62		
20	1.47	1.50			

Note. Each cell entry is a mean based on 80 trials, 20 trials for each of 4 subjects.

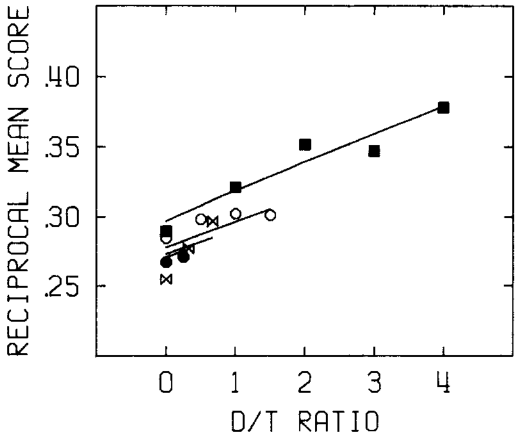

Figure 1. Group mean of reciprocated mean scores (number of correctly reported items) as a function of D/T ratio (number of distractors to number of targets) with T (number of targets) as a parameter for color condition of Experiment 1. (T was 5 [squares], 10 [open circles], 15 [hourglasses], or 20 [solid circles]. Unmarked points connected with straight lines represent a theoretical fit to the data by the three-parameter model.)

Figure 1 displays the group mean of reciprocated individual mean scores (averaged across target colors) as a function of D/T (the ratio of the number of distractors to the number of targets) with T as a parameter. A theoretical fit by the three-parameter model is indicated by unmarked points connected with straight lines. The fit accounts for 93.2% of the variance in the plotted data.[1] (The residual variance was minimized by an iterative method for searching the space of parameters. All parameters were treated as continuous; for nonintegral values of K, theoretical scores were calculated as weighted averages such that, for instance, a value of 3.8 for K was treated as a mixture of values of 3 and 4 with a probability of .8 for sampling four items on a trial. For any values of the three parameters, predicted scores were computed from the exact Equation 1, rather than the approximation ex-

[1] Equivalently, as scores for separate combinations of T and D are represented by separate data points in the plot, the fit accounts for 93.2% of the variance with T and D. A perfect fit of the model to the plotted data would imply that estimates for the same parameter based on different subsets of the plotted data be exactly the same. The percentage of variance accounted for by the fit thus reflects the extent to which the model provides a measure for efficiency of selection that is independent of T and D.

pressed in Equations 2 and 3. In consequence, the theoretical means do not strictly form a set of straight lines with a common slope.)

Fits of the three-parameter model to individual data are summarized in Table 2. Individual estimates for K, the number of items entering the buffer, averaged 4.0 letters. One unit being the impact of one target, individual estimates for the impact per distractor α averaged 0.07 units, and estimates for the total impact of extraneous noise items ϵ averaged 0.58 units.

Alphanumeric condition. The group mean score in the alphanumeric condition is shown in Table 3 as a function of target class (letter vs. digit), T, and D. Scores were higher, and there were fewer erroneously reported items for digit than for letter targets, but effects of T and D were similar for the two target classes. Averaged across target classes, the mean score was strictly a monotonic, increasing function of T (with D kept constant) and a monotonic, decreasing function of D (with T kept constant). The correlation between the mean score and the mean number of erroneously reported items as functions of T and D was −.45.

Probability correct varied between .772 (for $T = 5$, $D = 0$) and .191 (for $T = 20$, $D = 5$). It decreased with both T and D. Partial report superiority increased with D and decreased with T. Considering displays with $(T + D) = 20$, partial report superiority was 0.51 items for $T = 15$, 1.76 items for $T = 10$, and 4.50 items for $T = 5$.

Figure 2 displays the group mean of reciprocated individual mean scores (averaged across target classes) as a function of D/T ratio with T as a parameter. The indicated fit by

Table 2
Fits of Three-Parameter Model to Individual and Group Data for Color and Alphanumeric Conditions of Experiment 1

Subject	Parameter: K	α	ϵ	*RMSD*[a]	%V[b]
	Color condition				
1	4.43	0.156	1.46	0.217	88.7
2	3.83	0.053	0.00	0.234	57.4
3	3.08	0.040	0.57	0.119	76.6
4	4.49	0.040	0.28	0.118	88.0
Group[c]	3.79	0.067	0.41	0.103	91.3
	Alphanumeric condition				
1	4.95	0.365	0.68	0.181	96.4
2	4.15	0.218	0.00	0.152	95.3
3	3.34	0.147	0.38	0.111	93.7
4	4.07	0.344	0.07	0.230	91.2
Group[c]	4.01	0.255	0.22	0.096	98.0

Note. K = number of items entering the short-term memory buffer; α = impact per distractor with impact per target as the unit; ϵ = total impact of extraneous noise with impact per target as the unit.
[a] Quantity minimized by the fitting procedure: square root of the mean squared deviation (*RMSD*) between observed and predicted means for number of correctly reported items as a function of number of targets and number of distractors.
[b] Percentage of variance with number of targets and number of distractors accounted for by the fit.
[c] Harmonic means of individual subjects' mean scores treated as observed group data.

Table 3
Numbers of Correctly and Erroneously Reported Items as Functions of Target Type (Letter vs. Digit), Number of Targets, and Number of Distractors in Alphanumeric Condition of Experiment 1

Number of targets	Number of distractors: 0	5	10	15	20
	Correct with letter targets				
5	3.64	2.68	2.33	2.10	2.03
10	3.45	3.28	2.81	2.58	
15	3.75	3.20	2.91		
20	3.89	3.45			
	Correct with digit targets				
5	4.08	3.13	2.51	2.26	1.90
10	4.35	3.53	3.16	2.98	
15	4.44	3.89	3.65		
20	4.55	4.19			
	Errors with letter targets				
5	0.84	0.86	0.97	1.05	1.15
10	1.25	1.08	1.28	1.22	
15	1.08	1.18	1.19		
20	1.25	1.30			
	Errors with digit targets				
5	0.65	0.83	1.17	1.03	1.26
10	0.84	0.80	0.85	1.10	
15	0.90	0.69	0.89		
20	0.83	0.79			

Note. Each cell entry is a mean based on 80 trials, 20 trials for each of 4 subjects.

the three-parameter model accounts for 98.5% of the variance in the plot. Fits of the model to individual data are summarized in Table 2. Individual estimates for the parameters averaged 4.1 characters for K, 0.27 for α, and 0.28 for ϵ.

Experiment 2

Method

Partial reports were based on brightness (black vs. white), alphanumeric class, or shape (curved vs. straight). Number of targets T and number of distractors D were varied, and the number of targets correctly reported was recorded. The method was the same as that employed in Experiment 1 except as noted below.

Subjects. Five subjects participated in the experiment, including Subjects 1–4 from the previous experiment. Subject 5 was a female student, 24 years old, with normal vision.

Displays. The stimulus material consisted of 540 slides, 180 per condition, photographed from displays generated by computer on a color screen. The program constructing the displays was essentially the same as that used in Experiment 1. However, the cells in the 5 × 5 stimulus matrix were delineated by a rectangular grid, similar to that appearing on the response sheet. Grid and background were blue (5B 4/6 and 5B 5/6, respectively) and characters were either black or white. Under the experimental viewing conditions, a single character subtended approximately .37° in width and .46° in height. Center-to-center distance between adjacent characters in the same row of the 5 × 5 matrix was .92°. Center-to-center distance between adjacent characters in the same column was .97°.

Conditions. Characters in the brightness condition were black and white capital letters, chosen from a set of 20 consonants (Y excluded). The target set was either the black items or the white items. Characters in the alphanumeric condition were black capital letters (20 consonants) and digits (nine, excluding *0*). The target set was either the letters or the digits. All characters in the shape condition were black capital letters (20 consonants). The target set was either the curved items (*B, C, D, G, J, P, Q, R,* and *S*) or the straight items (*F, H, K, L, M, N, T, V, W, X,* and *Z*).

Procedure. The procedure was changed from the previous one by increasing exposure time to 100 ms. During projection of a slide, the pupils of the subject received an illuminance of about 0.4 lx from the stimulus field and 0.3 lx from the surroundings.

Design. The subjects served individually in one practice and three experimental sessions. Taken together, the three experimental sessions comprised six blocks of 180 experimental trials: one block for each of the two target sets for each of the three conditions. Order of blocks was counterbalanced with respect to the three conditions within subjects and varied between subjects.

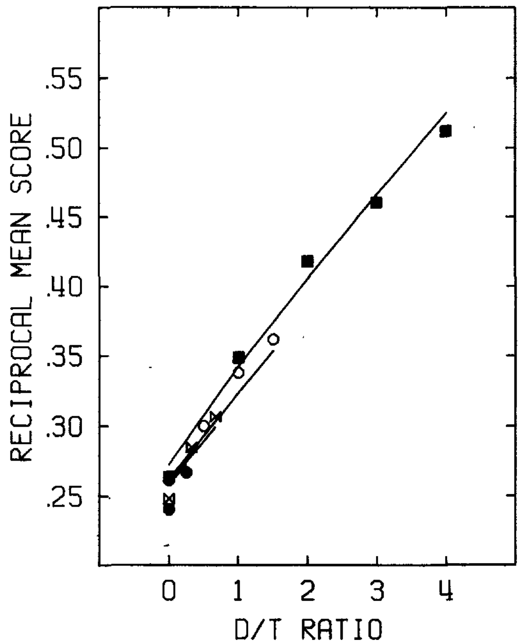

Figure 2. Group mean of reciprocated mean scores (number of correctly reported items) as a function of D/T ratio (number of distractors to number of targets) with T (number of targets) as a parameter for alphanumeric condition of Experiment 1. (T was 5 [squares], 10 [open circles], 15 [hourglasses], or 20 [solid circles]. Unmarked points connected with straight lines represent a theoretical fit to the data by the three-parameter model.)

Results

General pattern. Scores from the three conditions were different in magnitude, but for each condition the structure of the data was similar to that found in Experiment 1: The mean score (number of correctly reported items) increased with T (when D was kept constant) and decreased with D (when T was kept constant). The number of erroneously reported items showed less variation, and product-moment correlations between mean number of correctly and mean number of erroneously reported items as functions of T and D were weak. Probability correct (mean score divided by T) decreased with both T and D. Partial report superiority increased with D and decreased with T. Finally, the three-parameter model accounted for a high proportion of the variance in mean score as a function of T and D.

Brightness condition. Results from the brightness condition are shown in Table 4. Averaged across types of target (black vs. white), probability correct varied between .626 and .167. For displays with $(T + D) = 20$, partial report superiority was 1.03 items for $T = 15$, 2.56 items for $T = 10$, and 7.68 items for $T = 5$. The correlation between number of correctly and number of erroneously reported items was .06.

Figure 3 shows a fit of the three-parameter model to the group mean of reciprocated individual mean scores (averaged across target colors) as a function of D/T ratio with T as a parameter. The fit accounts for 85% of the variance in the plotted data. Fits of the model to individual data are summarized in Table 5. Individual estimates for the parameters averaged 3.6 letters for K, 0.02 for α, and 0.77 for ϵ.

Alphanumeric condition. Results from the alphanumeric condition are shown in Table 6. Averaged across types of target (letter vs. digit), probability correct varied between .602 and .155. For displays with $(T + D) = 20$, partial report superiority was 0.25 items for $T = 15$, 0.84 items for $T = 10$, and 2.16 items for $T = 5$. Correlation between number of correctly and number of erroneously reported items was −.02.

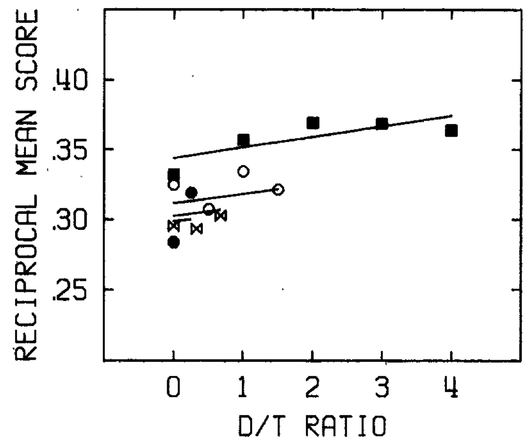

Figure 3. Group mean of reciprocated mean scores (number of correctly reported items) as a function of D/T ratio (number of distractors to number of targets) with T (number of targets) as a parameter for brightness condition of Experiment 2. (T was 5 [squares], 10 [open circles], 15 [hourglasses], or 20 [solid circles]. Unmarked points connected with straight lines represent a theoretical fit to the data by the three-parameter model.)

Table 4
Numbers of Correctly and Erroneously Reported Items as Functions of Target Type (Black vs. White), Number of Targets, and Number of Distractors in Brightness Condition of Experiment 2

Number of targets	Number of distractors: 0	5	10	15	20
	Correct with black targets				
5	3.08	2.68	2.66	2.82	2.74
10	3.24	3.18	3.04	3.20	
15	3.50	3.58	3.48		
20	3.70	3.42			
	Correct with white targets				
5	3.18	3.06	2.98	2.84	3.00
10	3.10	3.46	3.16	3.14	
15	3.42	3.42	3.30		
20	3.58	3.26			
	Errors with black targets				
5	0.48	0.66	0.60	0.40	0.36
10	0.54	0.70	0.58	0.44	
15	0.42	0.34	0.66		
20	0.32	0.62			
	Errors with white targets				
5	0.44	0.52	0.52	0.48	0.38
10	0.74	0.36	0.58	0.56	
15	0.52	0.60	0.66		
20	0.60	0.52			

Note. Each cell entry is a mean based on 50 trials, 10 trials for each of 5 subjects.

Figure 4 shows a fit of the three-parameter model to the group mean of reciprocated individual mean scores (averaged across target classes) as a function of D/T ratio with T as a parameter. The fit accounts for 98.9% of the variance in the data. Fits of the model to individual data, summarized in Table 5, gave estimates for the parameters averaging 3.9 characters for K, 0.49 for α, and 1.15 for ϵ.

Shape condition. Results from the shape condition are shown in Table 7. Averaged across types of target (curved vs. straight), probability correct varied between .564 and .129. For displays with $(T + D) = 20$, partial report superiority was 0.21 items for $T = 15$, 0.11 items for $T = 10$, and 1.09 items for $T = 5$. Correlation between number of correctly and number of erroneously reported items was .31.

Figure 5 shows a fit of the three-parameter model to the group mean of reciprocated individual mean scores (averaged across types

Table 5
Fits of Three-Parameter Model to Individual and Group Data for Brightness, Alphanumeric, and Shape Conditions of Experiment 2

	Parameter				
Subject	K	α	ϵ	*RMSD*[a]	%V[b]
	Brightness condition				
1	3.17	0.038	0.77	0.195	60.5
2	3.66	0.020	0.00	0.261	15.0
3	3.35	0.014	1.00	0.116	80.8
4	4.86	0.002	1.09	0.206	78.6
5	3.04	0.037	0.97	0.175	66.1
Group[c]	3.49	0.024	0.72	0.108	83.0
	Alphanumeric condition				
1	4.19	0.662	1.66	0.165	96.5
2	4.40	0.319	0.80	0.240	90.8
3	3.56	0.422	1.46	0.178	93.8
4	4.29	0.481	0.55	0.207	94.8
5	3.19	0.545	1.29	0.071	98.9
Group[c]	3.88	0.502	1.19	0.096	98.5
	Shape condition				
1	3.05	0.769	0.00	0.220	92.6
2	3.75	0.713	0.92	0.181	95.3
3	2.65	0.350	0.22	0.192	87.1
4	4.10	0.807	0.71	0.153	97.7
5	2.72	0.586	1.22	0.154	93.3
Group[c]	3.14	0.626	0.58	0.103	97.9

Note. K = number of items entering the short-term memory buffer; α = impact per distractor with impact per target as the unit; ϵ = total impact of extraneous noise with impact per target as the unit.
[a] Quantity minimized by the fitting procedure: square root of the mean squared deviation (*RMSD*) between observed and predicted means for number of correctly reported items as a function of number of targets and number of distractors.
[b] Percentage of variance with number of targets and number of distractors accounted for by the fit.
[c] Harmonic means of individual subjects' mean scores treated as observed group data.

of target) as a function of D/T ratio with T as a parameter. The fit accounts for 97.5% of the variance. Fits to individual data, summarized in Table 5, gave estimates averaging 3.3 letters for K, 0.65 for α, and 0.61 for ϵ.

General Discussion

Partial Report Superiority

All selection criteria investigated in Experiments 1 and 2 produced substantial partial report superiorities. Previous experiments have provided clear evidence of partial report superiority for selection by color (Clark, 1969; Dick, 1969, 1970, 1971; von Wright, 1968, 1970, 1972), brightness (von Wright, 1968), and shape (Turvey & Kravetz, 1970; von Wright, 1970). Early results on selection by alphanumeric class suggested that such selection "by category" occurred only to a very limited extent if at all (Sperling, 1960; von Wright, 1970). In later studies, partial report superiority was found for selection by alphanumeric class when timing and uncertainty of cues were equated across partial and whole report conditions (see Dick, 1969, 1970, 1971; Duncan, 1983; Merikle, 1980).

For every condition in Experiments 1 and 2, partial report superiority increased with the

Table 6
Numbers of Correctly and Erroneously Reported Items as Functions of Target Type (Letter vs. Digit), Number of Targets, and Number of Distractors in Alphanumeric Condition of Experiment 2

Number of targets	Number of distractors: 0	5	10	15	20
	Correct with letter targets				
5	3.02	2.02	1.52	1.32	1.32
10	3.26	2.72	2.36	2.26	
15	3.18	2.72	2.46		
20	3.46	2.88			
	Correct with digit targets				
5	3.00	2.20	1.78	1.74	1.28
10	3.84	2.94	2.44	2.14	
15	3.84	3.60	3.02		
20	4.46	3.32			
	Errors with letter targets				
5	0.50	0.58	0.40	0.48	0.40
10	0.52	0.54	0.36	0.36	
15	0.62	0.62	0.46		
20	0.46	0.52			
	Errors with digit targets				
5	0.82	0.42	0.64	0.46	0.60
10	0.40	0.76	0.40	0.92	
15	0.48	0.46	0.48		
20	0.40	0.40			

Note. Each cell entry is a mean based on 50 trials, 10 trials for each of 5 subjects.

number of distractors in the display (when number of targets was kept constant) and decreased with the number of targets (when number of distractors was kept constant).[2] Duncan (1983) reported a related result: For selection based on alphanumeric class, partial report superiority was greater for displays containing one target and five distractors than for displays with three targets and three distractors.

Model

The three-parameter model for partial report provided good fits to the data from Experiments 1 and 2. For the harmonic means of individual subjects' mean scores, the proportion of variance with number of targets T and number of distractors D accounted for by the model ranged between 83% and 98.5% with a median of 97.9% for the five experimental conditions. The proportion increased with the empirical variance, the square root of the mean squared deviation (*RMSD*) being about the same regardless of experimental condition (see Tables 2 and 5).

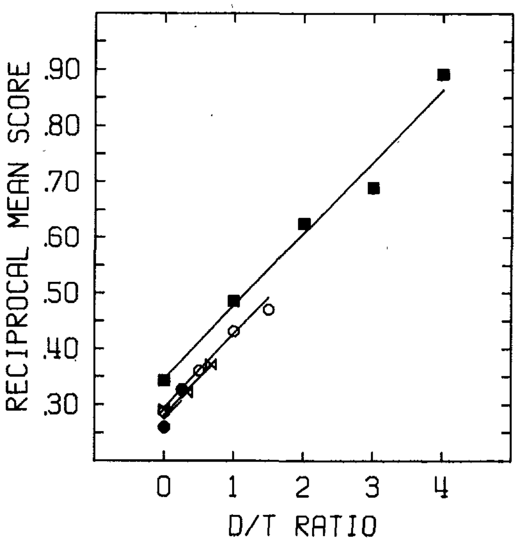

Figure 4. Group mean of reciprocated mean scores (number of correctly reported items) as a function of D/T ratio (number of distractors to number of targets) with T (number of targets) as a parameter for alphanumeric condition of Experiment 2. (T was 5 [squares], 10 [open circles], 15 [hourglasses], or 20 [solid circles]. Unmarked points connected with straight lines represent a theoretical fit to the data by the three-parameter model.)

Table 7
Numbers of Correctly and Erroneously Reported Items as Functions of Target Type (Curved vs. Straight), Number of Targets, and Number of Distractors in Shape Condition of Experiment 2

Number of targets	Number of distractors: 0	5	10	15	20
	Correct with curved targets				
5	2.88	1.96	1.30	1.20	1.04
10	3.30	2.70	1.80	1.66	
15	2.96	2.68	2.32		
20	3.36	2.70			
	Correct with straight targets				
5	2.76	1.58	1.40	1.00	1.00
10	2.82	2.16	1.62	1.50	
15	2.98	2.60	2.00		
20	3.26	2.46			
	Errors with curved targets				
5	0.66	0.46	0.40	0.34	0.32
10	0.50	0.30	0.46	0.24	
15	0.42	0.36	0.34		
20	0.22	0.18			
	Errors with straight targets				
5	0.66	0.44	0.20	0.26	0.34
10	0.60	0.16	0.40	0.38	
15	0.60	0.24	0.18		
20	0.32	0.36			

Note. Each cell entry is a mean based on 50 trials, 10 trials for each of 5 subjects.

The group mean of individual estimates for K (total number of items entering the short-term memory buffer) varied little across conditions, being 4.0 and 4.1 items in Experiment

[2] Our three-parameter model for partial report implies that if number of targets T and number of distractors D are large in relation to both parameter K and parameter ϵ, the expected number of correctly reported items is approximately $KT/(T + \alpha D)$. In a whole report condition with the same number of displayed items but no distractors, the expected score is nearly K items. Partial report superiority, then, is approximately a function of K, α, and D/T ratio, namely, $K(1 - \alpha)/[(T/D) + \alpha]$ items. By this approximation, partial report superiority is 0, if $\alpha = 1$. If $\alpha = 0$, partial report superiority is KD/T items. If $0 < \alpha < 1$, partial report superiority is an increasing, negatively accelerated function of D/T ratio, tending to 0, as D/T tends to 0, and tending to $K(1 - \alpha)/\alpha$ items, as D/T tends to infinity.

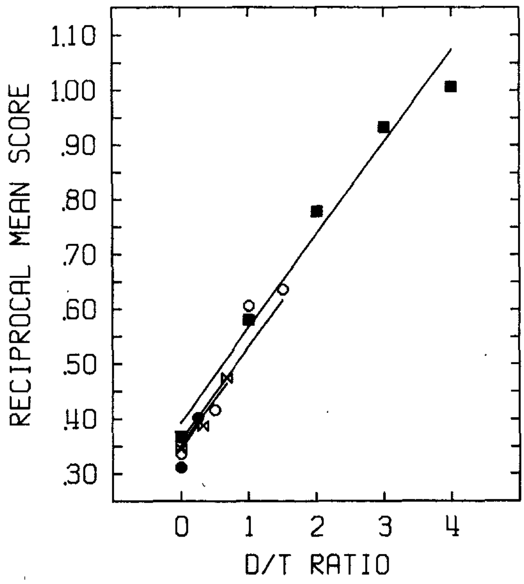

Figure 5. Group mean of reciprocated mean scores (number of correctly reported items) as a function of D/T ratio (number of distractors to number of targets) with T (number of targets) as a parameter for shape condition of Experiment 2. (T was 5 [squares], 10 [open circles], 15 [hourglasses], or 20 [solid circles]. Unmarked points connected with straight lines represent a theoretical fit to the data by the three-parameter model.)

1 and 3.6, 3.9, and 3.3 items in Experiment 2. Estimates for α (impact per distractor with impact per target as the unit) varied widely across conditions with group means ranging from .02 in the brightness condition of Experiment 2 to .65 in the shape condition of the same experiment. This variation in the efficiency of selecting targets rather than distractors corresponds to the strong variation in slope (i.e., the variation in effect of D/T ratio) between the functions depicted in Figures 1–5 (cf. Equations 2 and 3). Estimates for ϵ (total impact of extraneous noise items with impact per target as the unit) were rather small with group means ranging from 0.28 to 1.15. The effect of ϵ corresponds to the spacing between functions within Figures 1–5 (i.e., the effect of parameter T).

To summarize the results, Figure 6 displays the average of group means of reciprocated individual mean scores as a function of D/T ratio with T as a parameter across the five conditions in Experiments 1 and 2. The indicated fit by the three-parameter model accounts for 98.9% of the variance in the plotted data. Parameters K and α do most of the work. If parameter ϵ were kept constant at zero, the model would still account for 97.8% of the variance.

Limitations. The three-parameter model for partial report is limited in scope. The way the impact of a particular target or distractor element depends upon the position of that element in the visual field is not modeled (cf., e.g., Merikle & Glick, 1976; Wolford, 1975; Wolford, Wessel, & Estes, 1968), nor is the way in which sampling depends upon perceptual grouping of elements (cf. Fryklund, 1975; Kahneman & Henik, 1977, 1981; Keren, 1976; Merikle, 1980; see also Bundesen & Pedersen, 1983; Harms & Bundesen, 1983). Extensions in these directions should be explored.

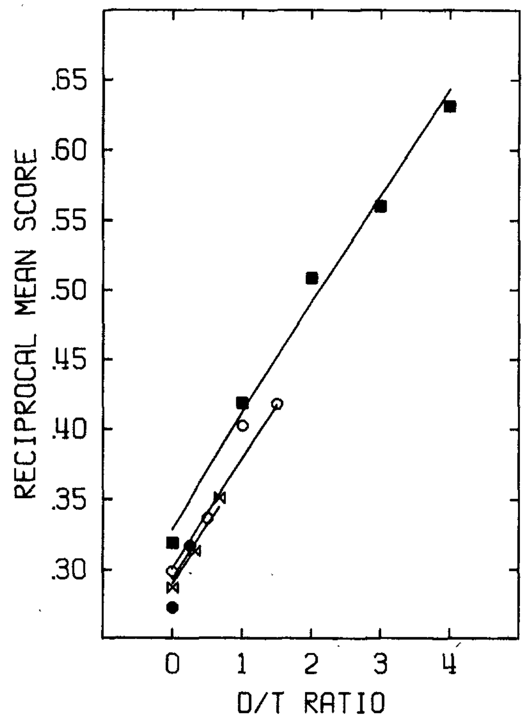

Figure 6. Average of group means of reciprocated mean scores (number of correctly reported items) as a function of D/T ratio (number of distractors to number of targets) with T (number of targets) as a parameter across all conditions of Experiments 1 and 2. (T was 5 [squares], 10 [open circles], 15 [hourglasses], or 20 [solid circles]. Unmarked points connected with straight lines represent a theoretical fit to the data by the three-parameter model.)

References

Averbach, E., & Coriell, A. S. (1961). Short-term memory in vision. *Bell System Technical Journal, 40,* 309–328.

Bundesen, C., & Pedersen, L. F. (1983). Color segregation and visual search. *Perception & Psychophysics, 33,* 487–493.

Clark, S. E. (1969). Retrieval of color information from preperceptual memory. *Journal of Experimental Psychology, 82,* 263–266.

Clarke, F. R. (1957). Constant-ratio rule for confusion matrices in speech communication. *Journal of the Acoustical Society of America, 29,* 715–720.

Coltheart, M. (1972). Visual information-processing. In P. C. Dodwell (Ed.), *New horizons in psychology* (Vol. 2, pp. 62–85). Harmondsworth, England: Penguin Books.

Coltheart, M. (1980). Iconic memory and visible persistence. *Perception & Psychophysics, 27,* 183–228.

Dick, A. O. (1969). Relations between the sensory register and short-term storage in tachistoscopic recognition. *Journal of Experimental Psychology, 82,* 279–284.

Dick, A. O. (1970). Visual processing and the use of redundant information in tachistoscopic recognition. *Canadian Journal of Psychology, 24,* 133–141.

Dick, A. O. (1971). On the problem of selection in short-term visual (iconic) memory. *Canadian Journal of Psychology, 25,* 250–263.

Duncan, J. (1983). Perceptual selection based on alphanumeric class: Evidence from partial reports. *Perception & Psychophysics, 33,* 533–547.

Fryklund, I. (1975). Effects of cued-set spatial arrangement and target-background similarity in the partial-report paradigm. *Perception & Psychophysics, 17,* 375–386.

Harms, L., & Bundesen, C. (1983). Color segregation and selective attention in a nonsearch task. *Perception & Psychophysics, 33,* 11–19.

Kahneman, D., & Henik, A. (1977). Effects of visual grouping on immediate recall and selective attention. In S. Dornic (Ed.), *Attention and performance VI* (pp. 307–332). Hillsdale, NJ: Erlbaum.

Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization* (pp. 181–211). Hillsdale, NJ: Erlbaum.

Keren, G. (1976). Some considerations of two alleged kinds of selective attention. *Journal of Experimental Psychology: General, 105,* 349–374.

Luce, R. D. (1959). *Individual choice behavior.* New York: Wiley.

Luce, R. D., Bush, R. R., & Galanter, E. (1963). *Handbook of mathematical psychology* (Vol. 1). New York: Wiley.

Merikle, P. M. (1980). Selection from visual persistence by perceptual groups and category membership. *Journal of Experimental Psychology: General, 109,* 279–295.

Merikle, P. M., & Glick, M. J. (1976). Processing order in visual perception. *Quarterly Journal of Experimental Psychology, 28,* 17–26.

Neisser, U. (1967). *Cognitive psychology.* New York: Appleton-Century-Crofts.

Schumann, F. (1904). Die Erkennung von Buchstaben und Worten bei momentaner Beleuchtung [Recognition of briefly exposed letters and words]. In F. Schumann (Ed.), *Bericht über den ersten Kongress für experimentelle Psychologie* (pp. 34–40). Leipzig, Germany: Barth.

Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs, 74*(11, Whole No. 498).

Sperling, G. (1963). A model for visual memory tasks. *Human Factors, 5,* 19–31.

Sperling, G. (1967). Successive approximations to a model for short-term memory. *Acta Psychologica, 27,* 285–292.

Turvey, M. T., & Kravetz, S. (1970). Retrieval from iconic memory with shape as the selection criterion. *Perception & Psychophysics, 8,* 171–172.

Wolford, G. (1975). Perturbation model for letter identification. *Psychological Review, 82,* 184–199.

Wolford, G. L., Wessel, D. L., & Estes, W. K. (1968). Further evidence concerning scanning and sampling assumptions of visual detection models. *Perception & Psychophysics, 3,* 439–444.

von Wright, J. M. (1968). Selection in visual immediate memory. *Quarterly Journal of Experimental Psychology, 20,* 62–68.

von Wright, J. M. (1970). On selection in visual immediate memory. *Acta Psychologica, 33,* 280–292.

von Wright, J. M. (1972). On the problem of selection in iconic memory. *Scandinavian Journal of Psychology, 13,* 159–171.

Received May 3, 1983
Revision received November 7, 1983 ■