*Research Report*

# Temporal Limits of Selection and Memory Encoding

## A Comparison of Whole Versus Partial Report in Rapid Serial Visual Presentation

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ABSTRACT—***People often fail to recall the second of two visual targets presented within 500 ms in rapid serial visual presentation (RSVP). This effect is called the attentional blink. One explanation of the attentional blink is that processes involved in encoding the first target into memory are slow and capacity limited. Here, however, we show that the attentional blink should be ascribed to attentional selection, not consolidation of the first target. Rapid sequences of six letters were presented, and observers had to report either all the letters (whole-report condition) or a subset of the letters (partial-report condition). Selection in partial report was based on color (e.g., report the two red letters) or identity (i.e., report all letters from a particular letter onward). In both cases, recall of letters presented shortly after the first selected letter was impaired, whereas recall of the corresponding letters was relatively accurate with whole report.***

Many common tasks, such as reading and visual search, require that one repeatedly and rapidly update the contents of working memory with new perceived information. Studies using a dual-task approach suggest that such memory updating is a slow, capacity-limited process, as they show that performance is impaired on tasks performed concurrently with or shortly after the presentation of a to-be-remembered target. For example, observers often fail to recall visual targets presented within 500 ms of a first target in rapid serial visual presentation (RSVP; Broadbent & Broadbent, 1987; Chun & Potter, 1995; Weichselgartner & Sperling, 1987), an effect called the attentional blink (Raymond, Shapiro, & Arnell, 1992), and reaction times to stimuli presented shortly after a to-be-reported target are often slow (Jolicoeur & Dell'Acqua, 1998).

Interpreting these findings as evidence for a memory-based limitation is problematic, however, because all these tasks require observers to select the targets that have to be remembered, and it is possible that selection by itself incurs a cost in processing subsequent events (Weichselgartner & Sperling, 1987). To differentiate between the costs of selection and of encoding, one should compare a condition in which observers report all items presented in RSVP (whole report) and a condition in which they have to report only a subset of the items (partial report). Both these conditions require encoding letters into memory, but only the partial-report condition requires the selection of to-be-reported items. In this article, we report two experiments that examined the potential cost of attentional selection by comparing partial and whole report in an RSVP task. In the first experiment, selection for partial report was based on color (e.g., report only the two red letters), and in the second experiment, selection was based on identity (i.e., report all letters from a particular letter onward).

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## EXPERIMENT 1

### Method

#### *Participants*

Twelve members of the Massachusetts Institute of Technology community (7 female; mean age = 24.4 years) volunteered and were paid for participation. All had normal or corrected-to-normal vision, and none was color-blind.

#### *Apparatus and Stimuli*

The stimuli were uppercase letters (excluding *I*, *O*, *W*, and *M*), presented in a 36-point Helvetica font. Each letter was red, green, or blue and appeared on a dark gray background. The RGB values for red, green, blue, and gray were (108 0 0), (0 70 0), (0 0 108), and (90 90 90), respectively. The experiment was run in a normally illuminated room using an Apple Macintosh G4 computer. Stimuli appeared at a resolution of 1024 × 768 pixels on a 17-in. monitor, running at 75 Hz. Stimulus presentation was controlled using MATLAB and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997).

### *Design and Procedure*

Each trial consisted of an RSVP sequence of six colored, uppercase letters, preceded and followed by a black fixation cross. Each letter was presented for 67 ms and followed by a 40-ms blank interval, yielding a presentation rate of 107 ms per item. Two letters were presented in red, two in blue, and two in green, in pseudorandom order. In the whole-report condition, observers were instructed to report as many letters from the sequence as they could. In the partial-report condition, observers were to report two letters presented in a particular color.

There were three blocks of 42 trials, one block for each target color, in the partial-report condition. These partial-report blocks were interleaved with whole-report blocks of the same length. The order in which the three partial-report blocks were run was counterbalanced across observers, and half of the observers began with a whole-report block. Each block of trials was preceded by eight practice trials. Observers were required to type in the requisite number of letters for each condition (i.e., six in whole report and two in partial report), so they had to guess the letters they could not remember. They were told that the six letters would always be different letters, and that they could enter their responses in any order.

The structure of the trial sequences was the same for the whole- and partial-report conditions. The letters were randomly selected on each trial. As noted, there were 42 trials for each target color in the partial-report condition. On 24 of these trials, the two targets (T1 and T2) were separated by a single distractor (Lag 2), with T1 occurring equally often in Serial Positions 1 through 4. On the remaining trials, the targets were presented at Lag 3, 4, or 5 (9, 6, and 3 trials, respectively). Note that the frequency of occurrence of the different lags and T1 serial positions could not be balanced because there were only six positions in which the targets could be presented. The order of the different trial types was randomized in each block. The 42 trials in each block in the whole-report condition paralleled those in the partial-report condition.

### *Data Analyses*

Recall of T1 and T2 in partial report was compared with recall of nominally the same letters in whole report. For these analyses, the data were collapsed across serial positions of the targets; trials in which T2 appeared in the last position were excluded because of the absence of a masking stimulus after the last letter. The difference between T2 recall in whole versus partial report was analyzed separately for Lags 2, 3, and 4, using only those trials on which T1 (or the corresponding letter in whole report) was reported correctly. Significance of the results is reported in terms of $p_{rep}$, which denotes the probability of replication (Killeen, 2005).

### Results

Figure 1a shows recall performance averaged across all trials for letters in the first five serial positions in whole report and for T1 and T2 in the partial-report condition; T2 performance is plotted separately for the different lags. On average, in whole report, observers recalled 3.4 out of the first 5 letters (4.1 out of all 6), and probability of recall decreased across serial positions, $F(1, 11) = 42.93$, $p_{rep} = .997$, $\eta^2 = .795$.

Figure 1b shows the data for T1 and T2 recall that were used for the statistical comparison between whole and partial report. T1 recall did not differ significantly between whole and partial report ($M$ = 76% vs. 81% correct). At Lag 2, there was a substantial impairment in T2 recall in the partial-report condition ($M$ = 60% vs. 37% correct for whole and partial report, respectively), $t(11) = 3.25$, $p_{rep} = .957$, $d = 1.59$. There was no significant difference in T2 recall at Lag 3, but recall was significantly better with partial than with whole report at Lag 4, $t(11) = 2.47$, $p_{rep} = .906$, $d = 1.20$. These results reflect the fact that T2 recall increased rapidly across lags in the partial-report condition, as T2 recovered from an attentional blink, whereas T2 recall decreased across lags in the whole-report condition, as a consequence of the increasing memory load (see Fig. 1b). The role of memory limitations in whole-report performance is further illustrated by the fact that report of the fifth letter was equally accurate when two or three of the previously presented letters were recalled correctly ($M$ = 61 and 58% correct, respectively), but dropped to 44% correct when all four previous letters were reported correctly.

## EXPERIMENT 2

### Method

The aim of Experiment 2 was to replicate the finding of whole-report superiority in a task in which selection for partial report was based on letter identity instead of color. Such a replication would eliminate the possibility that the difference in T2 performance observed in Experiment 1 was caused by the fact that partial report required the binding of color and identity information (e.g., detect red and then identify the letter), whereas color was irrelevant in whole report. The partial-report condition in Experiment 2 required participants to report all the letters beginning with a particular letter, the cue letter (for a similar method, see Weichselgartner & Sperling, 1987).

In Experiment 2, all six letters appeared in black. Each was presented for 67 ms and followed by a 40-ms blank interval, yielding a presentation rate of 107 ms per item. Whole report required observers to report as many letters from the sequence

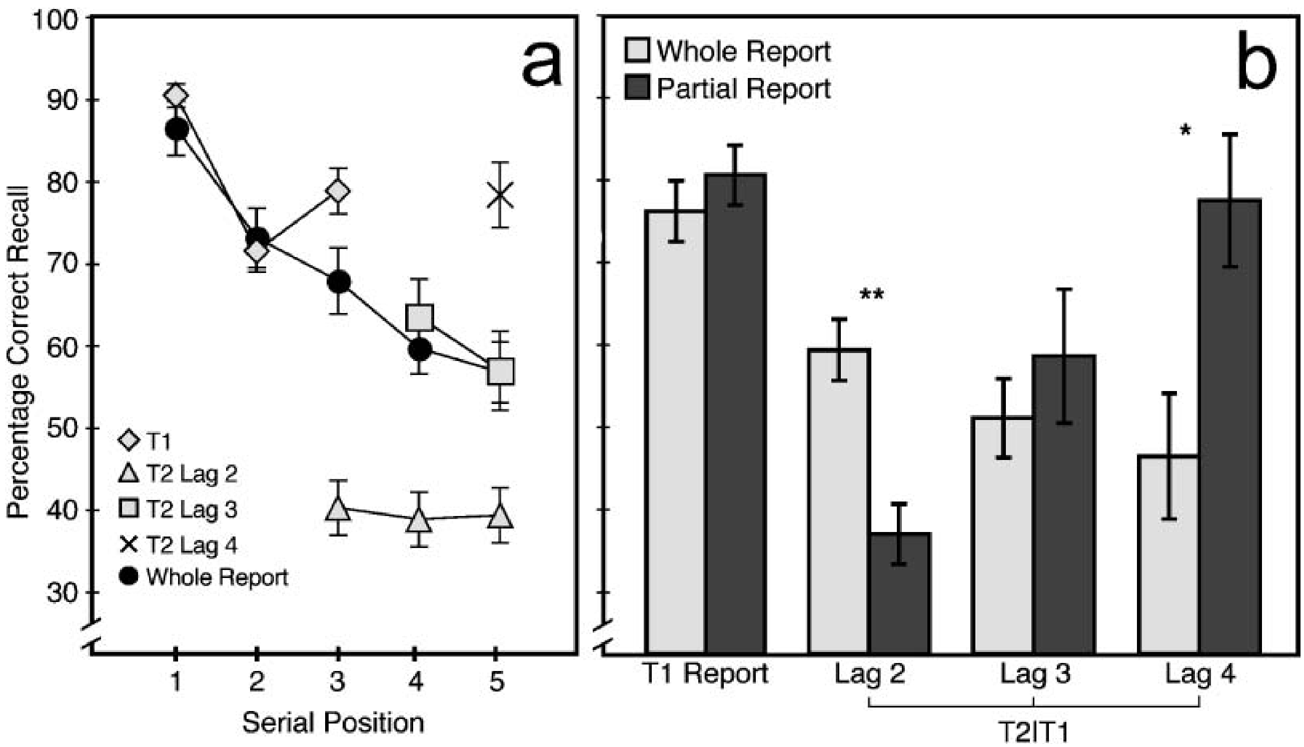


**Fig. 1.** Results from Experiment 1. The graph in (a) shows recall averaged across all trials for the whole-report condition and for the first and second targets (T1 and T2) in the partial-report condition, plotted as a function of serial position. T1 recall is collapsed across lags, and T2 recall is shown separately for the different lags. The graph in (b) shows average T1 recall for the whole- and partial-report conditions, and T2 recall across lags for trials on which T1 or the corresponding letter in whole report was reported correctly (T2 | T1). Error bars indicate standard errors of the mean. Asterisks indicate a significant difference between the whole- and partial-report conditions, $^*p_{rep} > .87$, $^{**}p_{rep} > .95$.

as they could, but they were not required to guess. In the partial-report condition, each trial began with the presentation of a cue letter that indicated the beginning of the sequence of letters participants were to report. The cue letter was presented for 1,000 ms, followed by a fixation cross for 400 ms and then the sequence. The task was to search for the cue letter and to report this letter and all letters that followed it. As in whole report, they were not required to guess. In both report conditions, observers were asked to type in the letters they thought they remembered in the order in which they appeared.

In the partial-report condition, the cued letter appeared 24 times each in Serial Positions 1 and 2, and 6 times each in Serial Positions 3 through 6. The latter trials were considered filler trials and were not analyzed. There were 72 trials in the partial-report condition, and an equal number of trials were constructed for the whole-report condition. The conditions were run in separate blocks. Order of the blocks was counterbalanced across subjects. Sixteen new observers (10 female, mean age = 22.1), drawn from the same pool as that used in Experiment 1, volunteered to participate in this experiment and were paid. All had normal or corrected-to-normal vision.

**Results**

Reports were scored without regard to serial order. Figure 2a shows recall of letters across serial positions (excluding Position 6) for both the whole-report condition and the partial-report conditions in which the cue appeared at Position 1 or 2. On average, in whole report, 3.5 letters out of 5 were correctly reported (4.2 out of all 6), and recall performance declined across serial positions, $F(1, 15) = 47.93$, $p_{rep} = .999$, $\eta^2 = .762$. For analysis of the difference in recall performance between whole report and partial report, we computed the means for the first 3 letters following the cued letter in partial report (i.e., letters appearing at Lags 1, 2, and 3) and compared these means with those for the corresponding letters in whole-report trials on which the letter corresponding to the cued letter was reported correctly (Fig. 2b).

The main result was a significant interaction of report condition and lag, $F(2, 30) = 6.33$, $p_{rep} = .965$, $\eta^2 = .297$, with partial report showing an impairment for letters appearing shortly after the cued letter. Note that performance in partial report did not improve across lags, as it did in Experiment 1, which may reflect the fact that the effect of an increasing memory load counteracted the gradual recovery from selection of the cued letter. The serial position of the cued letter (1 or 2) did not affect the interaction between report condition and lag, $F < 1$ for the three-way interaction of position of the cued letter, report condition, and lag. Thus, the allocation of attention to the cued letter led to impaired recall of following letters, even when the cued letter was the first letter in the sequence and hence there was no need to ignore letters appearing before or after it.

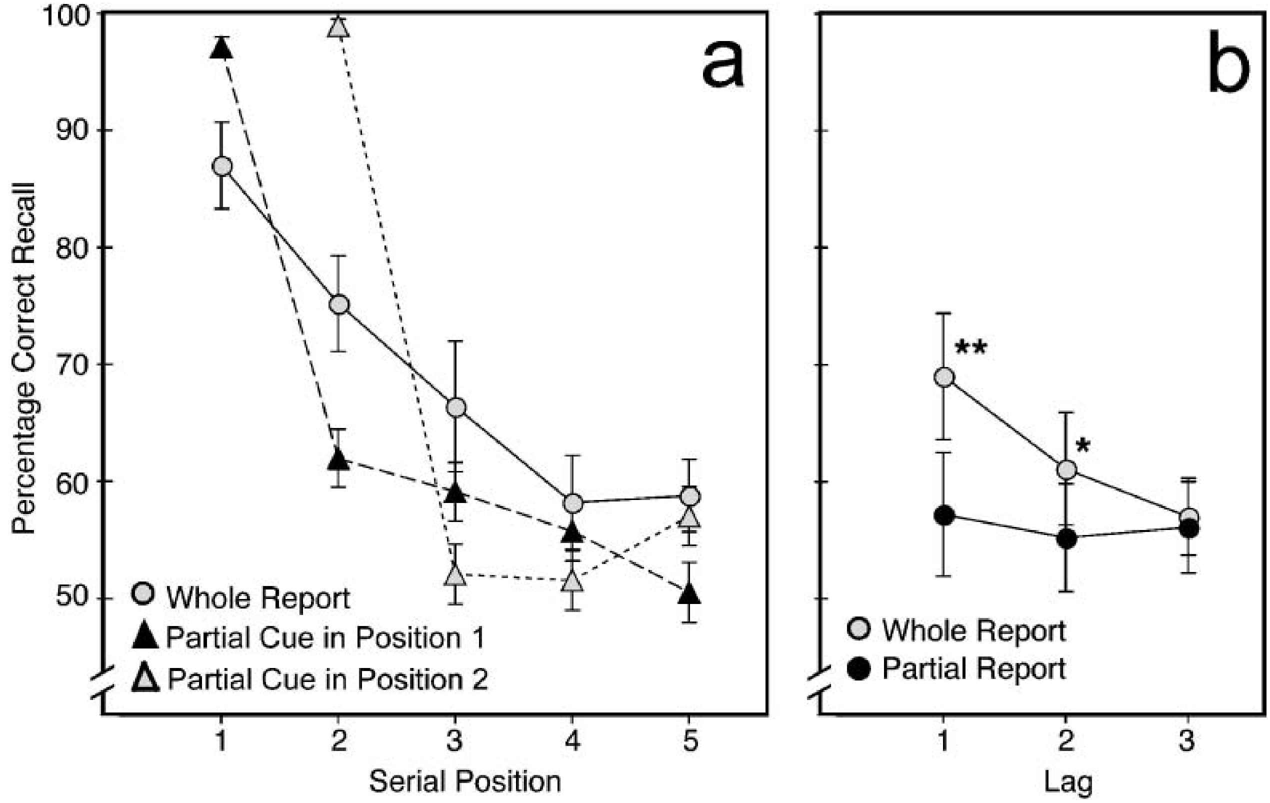


**Fig. 2.** Results from Experiment 2. The graph in (a) shows recall performance across serial positions for whole-report trials and for partial-report trials in which the cued letter appeared at Serial Position 1 or 2. The graph in (b) shows performance for letters appearing at Lags 1, 2, and 3 for trials on which the cued letter or the corresponding letter in whole report was reported correctly. Error bars indicate standard errors of the mean. Asterisks indicate a significant difference between the whole- and partial-report conditions, *$p_{rep} > .87$, **$p_{rep} > .95$.

## DISCUSSION

The present study shows that recall of letters presented shortly after a first selected letter in partial report is impaired, whereas recall of the corresponding letters is relatively accurate with whole report. This whole-report superiority stems from the difficulty of recalling letters that follow shortly after the first selected letter in partial report. This impairment in partial report cannot be ascribed to limits of memory encoding, as recall of the same letters is relatively accurate in whole report, even though whole report requires more letters to be stored in memory than partial report does. Instead, the results are consistent with the view that the attentional blink occurs because the allocation of attention to stimuli following a first selected stimulus is delayed (Nieuwenstein, Chun, Van der Lubbe & Hooge, 2005). The conclusion that memory consolidation of T1 is not responsible for the attentional blink is consistent with other findings showing that people can accurately recall three consecutive targets (Di Lollo, Kawahara, Ghorashi, & Enns, 2005) or even whole sentences presented one word at a time with RSVP (Potter, 1999), and that memory encoding can occur at rates as high as 50 ms per object (Vogel & Luck, in press).

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