A note on sequential blanking

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Five-letter pseudowords were presented in all possible spatiotemporal orders at each of nine combinations of letter duration and interletter interval. Subjects were required to report as many letters of the pseudoword as possible. The results confirmed the sequential blanking effect; under certain timing conditions, some spatiotemporal orders result in perceptual blanking. The results show, however, that blanking does not follow the two rules previously thought to describe the phenomenon.

Suppose a five-letter word is shown in a letter-by-letter manner on a cathode-ray tube. Each letter is presented for 20 msec and takes its appropriate spatial position; the interletter interval is also 20 msec. The time of arrival for particular letters is determined by the spatiotemporal order of presentation. When the letters are presented in a regular spatiotemporal order—from left to right (12345)¹ or from right to left (54321)—all can be seen clearly. If the letters are presented in particular irregular orders, however, some of the letters will not be seen. For example, presentation of the word CHAIR in order 31425 will appear as C _ A _ R on the screen.

Such disappearance of particular characters has been termed "sequential blanking," and preliminary studies of the effect have been provided by Mayzner and his colleagues. As Mayzner and Tresselt (1970) indicate in their review, the phenomenon has been documented using a variety of stimulus characters, character configurations, and display sizes. Although Mayzner's group has provided the bulk of the data, the phenomenon has been confirmed independently. In a forced-choice study examining the "fate" of blanked items, Pollack (1972) indicated that blanked material provides residual information and that item spacing is not a critical factor.

Although blanking has been demonstrated in a wide variety of situations, current evidence does not give a complete picture of the phenomenon. In particular, no study provides more than a few examples of display parameters, i.e., orders and timings, which produce the effect. Generalizing from the cases examined, however, Mayzner and Tresselt (1970) have suggested two rules to summarize the evidence. Their first rule concerns the timing of the whole display; blanking cannot occur unless the total time

between the onset of the first character and the offset of the final character lies between 100 and 300 msec. The optimal time is thought to be about 200 msec. Their second rule concerns the spatiotemporal order of presentation. Given an appropriate total-time value, a particular item will be blanked when a spatially adjacent item follows it by about 100 msec.²

The present study examined blanking by presenting five-letter displays in all of the 120 (5!) possible orders. Each display order was tested under nine combinations of letter duration and interletter interval. The combinations provide both a range of total display times (from 151 to 249 msec) and a variety of timings between spatially adjacent items.

METHOD

Subjects

The subjects were 30 volunteers from the undergraduate classes of Queen's University. All subjects reported normal or corrected-to-normal vision.

Materials and Apparatus

Five-letter pseudowords of second-order approximation to English were generated using the bigram frequencies provided by Baddeley, Conrad, and Thomson (1960). Three hundred and sixty pseudowords without repeated letters were selected for use in the experiment. The materials were presented on a Tektronix 604 display monitor supplied with P4 phosphor and controlled by a PDP-8/e computer. The monitor was housed in a partially darkened room. Each letter was presented in upper case by brightening the appropriate dots of a matrix of 7 rows by 5 columns. A single letter subtended a maximum visual angle of about $15' \times 21'$; a complete pseudoword subtended an angle of approximately $1^{\circ}53' \times 21'$.

Design

Subjects were assigned randomly to one of three equal groups defined in terms of letter duration. The letter durations were 15, 20, and 25 msec. For each subject, three interletter intervals and all of the 120 (5!) possible presentation orders were used. The interletter intervals were 19, 25, and 31 msec.

Each subject received 360 trials, one for each combination of interletter interval and presentation order. Each pseudoword was used once for each subject. Both the ordering of trials and the pairing of pseudowords to the combinations of presentation order and interletter interval were randomized independently for each subject.

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Procedure

At the beginning of each trial, a fixation dot was present. When ready, the subject initiated the trial by pushing a button; the fixation dot was removed, and the five letters of the pseudoword were displayed with the presentation order and timing appropriate to the trial. The subjects responded by reporting as many of the letters as possible; no restrictions concerning order of report were imposed. The responses were scored by counting the number of letters reported correctly regardless of the order of report.

Before starting the experiment proper, the subjects were given two sets of 20 practice trials. The first set was administered to acquaint the subjects with simple tachistoscopic procedures and involved free-recall of single pseudowords. The letters of each pseudoword were presented simultaneously for 100 msec. The second set of practice trials served to illustrate the blanking phenomenon and to familiarize the subjects with sequential displays. Three kinds of sequential display were used, left-to-right, right-to-left, and displays in the 31425 presentation order. Both the letter duration and the interletter interval were 20 msec, parameters which are known to yield strong blanking with the 31425 presentation order.

RESULTS AND DISCUSSION

Table 1 shows the percentage of letters reported correctly as a function of letter duration and interletter interval. The data are collapsed across subjects, 120 presentation orders, and 5 stimulus positions. An analysis of variance revealed a small but significant effect of letter duration, $F(2,54) = 4.45$, $p < .02$. Mean performance for the 15-, 20-, and 25-msec durations was 79.0%, 81.8%, and 83.2%, respectively. Neither the interletter interval factor nor the interaction of letter duration with interletter interval yielded significant effects.

Blanking, by definition, results in low performance. Low performance, however, may occur for a variety of random or artifactual reasons. The fundamental problem, then, is that of distinguishing low performance due to artifact from that due to blanking. Given that blanking is systematic and can, thereby, be distinguished from artifact, the subsequent analyses attempt to isolate systematic instances of low performance.

The first attempt to isolate blanking is based on the total-display-time rule. Blanking is thought to occur when the total-display time lies between 100 and 300 msec, with the optimal effect at about 200 msec. The total times in the present experiment span the

Table 2
Percentage of Letters Reported Correctly
as a Function of Total-Display Time

Total-Display Time				
151	175-176	199-201	224-225	249
79.4	80.8	81.3	82.0	83.1

middle of the critical range (from 151 to 249 msec). If blanking were maximized at about 200 msec, performance should take a quadratic trend across the range.

Table 2 presents the data from Table 1 recast in terms of total-display time. Performance across the range of total-display times was fairly flat, but there was a small trend indicating an increase in performance as the time increased. The latter result is not consistent with the total-display-time rule. Nevertheless, two considerations remain. First, it is possible that the range of times is not large enough to reveal the quadratic trend. Second, each percentage in the table represents a minimum of 6,000 observations. Blanking may have been sufficiently rare that the averaging inherent in the analysis concealed it.

To provide a more sensitive test of the rule, performance at each spatial position of each presentation order was calculated for all nine total-display times. Performance was measured by counting the number of subjects correct at each spatial position. With 10 subjects receiving each combination of presentation order and timing, the range of possible scores is 0.0-1.0 in steps of 0.1. For each total-display time, a distribution was calculated recording the frequency associated with each level of performance. The distributions for like total-display times were combined to yield five frequency distributions, one for each of the 151-, 175-176-, 199-201-, 224-225-, and 249-msec total-display-time categories. Because performance was measured in terms of the number of subjects correct, the number of cases associated with each category was 600, 1,200, 1,800, 1,200, and 600, respectively. To aid comparison among the distributions, they were converted first from simple frequency distributions to cumulative frequency distributions and then to cumulative proportions.

If blanking is isolated within particular total-display-time categories, those categories should contain a relatively larger proportion of low-performance cases. For such categories, the cumulative proportion curves should rise more quickly than for categories which do not include blanking elements. Thus, a plot of the cumulative proportion of cases against the performance level should permit an easy discrimination of categories which include blanking elements.

Figure 1 shows the cumulative proportion of cases associated with each level of performance for the five

Table 1
Percentage of Letters Reported Correctly as a Function
of Letter Duration and Interletter Interval

Letter Duration								
15 msec			20 msec			25 msec		
Interletter Interval			Interletter Interval			Interletter Interval		
19	25	31	19	25	31	19	25	31
79.4	79.3	78.3	82.3	81.9	81.1	83.6	82.9	83.1

Figure 1. The cumulative proportion of cases as a function of level of performance and total-display-time category.

total-display-time categories. As is shown in the figure, an appreciable proportion of cases involved low levels of performance. Unfortunately, the cumulative curves were remarkably similar; with the possible exception of the 249-msec total-display time, all total times yielded equivalent distributions of performance. Consequently, at least over the range explored here, application of the total-time rule does not distinguish blanking from other instances of low performance.

The next analysis is based on the spatial-adjacency rule and, like the preceding one, considers performance for each letter within each combination of presentation order and timing. An algorithm was constructed which calculates the interstimulus interval between spatially adjacent characters. The adjacency rule suggests that a particular item will be blanked, when a spatially adjacent item follows it by about 100 msec. Thus, the algorithm can be used to predict blanking by calculating the interstimulus interval between spatially adjacent items. Assuming "about 100 msec" means 100 ± 20 msec, the algorithm was used to sort the data into cases predicted to blank and cases predicted not to blank.³

Table 3 presents the percentage of letters reported correctly for the cases predicted to blank and for those predicted not to blank. With 10 subjects, 120 display orders, and 5 spatial positions, 6,000 observations were sorted for each combination of interletter interval and letter duration. Accordingly, the table includes the percentage of the cases associated with each prediction. Performance on letters predicted to blank was about 14% lower than that on those predicted not to blank, $F(1,27) = 111.06$, $p < .001$, a fact indicating that the prediction rule has some merit. It is clear, however, that the rule is not sufficient; performance on letters predicted to blank was very high (71%). The high performance on letters predicted to blank indicates that the prediction rule has not isolated the instances of very low performance evident in the first figure.⁴ Thus, the adjacency rule appears to have some predictive power, but it certainly does not capture the phenomenon.

The results presented so far are somewhat discouraging. Sequential blanking is, subjectively, a remarkably convincing effect. Indeed, all 30 subjects remarked on its power during the demonstration-practice trials. Nevertheless, the two rules abstracted from sample cases, the total-display-time and spatial-adjacency rules, do not describe the necessary display parameters. Indeed, the rules do not isolate systematic instances of low performance sufficiently to confirm the basic blanking phenomenon. Thus, despite the wide variety of timings, display contents, and

Table 3
Percentage of Letters Reported Correctly for Cases Predicted to Blank and Not to Blank by the 100 ± 20 -msec Algorithm

Interletter Interval																	
19						25						31					
Letter Duration						Letter Duration						Letter Duration					
15	20	25	15	20	25	15	20	25	15	20	25	15	20	25	15	20	25
B*	N	B	N	B	N	B	N	B	N	B	N	B	N	B	N	B	N
62	83	64	86	77	86	68	86	74	84	76	85	69	81	71	84	77	85
16†	84	16	84	24	76	36	64	24	76	24	76	24	76	24	76	24	76

*B = Predicted to blank; N = Predicted not to blank. †Percentage of cases contributing to the prediction. The number of observations at each interletter interval and duration combination is 6,000.

display sizes from which they have been abstracted, the rules appear to be generalizations from too few presentation orders.

Although the total-display-time rule did not distinguish blanking from other instances of low performance, the spatial-adjacency rule is at least partially successful. There are two components to the latter rule. First, it stipulates that an item is blanked by a spatially adjacent item which follows it. Second, it posits a critical interstimulus interval. Note that by stipulating only one spatially adjacent item, the rule merges several different situations. For example, a particular letter can be followed by two flankers or preceded by one and followed by the other. The adjacency rule treats both cases equivalently. Thus, the rule could have failed because it merged non-equivalent cases and/or because the critical interstimulus interval is incorrect.

To consider the latter possibilities, it is convenient to characterize each letter in terms of the interstimulus intervals to the spatially adjacent letters. Thus, each character can be represented in a two-dimensional space with the interstimulus interval to the letter at the left on the x-axis and that to the letter at the right on the y-axis. For each trial, then, five pairs of coordinates are generated. A negative coordinate is assigned if the flanker precedes and a positive one if the flanker follows. Of course, for the leftmost letter, the x value is not defined, and an arbitrary zero value is assigned. Similarly, for the rightmost letter, an arbitrary zero is assigned as the y value. Because a completely sequential display does not yield a real zero value for any case, the arbitrary assignments should not cause confusion.

With the coordinate system in mind, all cases can be classified into eight categories: $(0, \pm y)$ and $(\pm x, 0)$ for the leftmost and rightmost characters and $(\pm x, \pm y)$ for those letters flanked on both sides. To consider the equivalence of the cases merged by the adjacency rule, the data were sorted into the eight categories. As before, performance at each spatial position was measured by counting the number of subjects correct. The number of instances associated with each of the $(+x, +y)$ and $(-x, -y)$ categories was 1,080; each other category involved 540 instances. For each category, a distribution was calculated recording the frequency associated with each level of performance. As before, the frequency distributions were converted first to cumulative frequency distributions and then to cumulative proportions. If blanking is isolated within any of the eight categories, those categories should contain relatively more cases of low performance. Consequently, a plot of cumulative proportion of cases against level of performance should permit discrimination of the relevant categories.

Figure 2 summarizes performance in terms of the eight categories. The figure shows the cumulative proportion of cases associated with each level of performance as a function of the category.

Instances of low performance occurred in only two categories, those with interstimulus relations of $(+x, +y)$ and $(+x, 0)$. Otherwise, performance was uniformly high; in 95% of the other cases, accuracy of report was at least 0.7. Thus, in contrast to the previous analyses, an examination of the interstimulus relations in detail isolates virtually all cases of very low performance. Such isolation (finally) confirms the blanking effect.

Both categories yielding low performance represent a backward-masking or metacontrast paradigm. The $(+x, +y)$ category refers to situations in which both flanking letters follow the reference item. The $(+x, 0)$ category identifies a rightmost letter followed by its adjacent flanker. Curiously, the present data show a spatial asymmetry; minimum performance in the $(0, +y)$ category—the leftmost letter followed by its adjacent flanker—was 0.5.

Figure 2. The cumulative proportion of cases as a function of level of performance and categories of the interstimulus interval space.

Because blanking seems to be isolated within the two categories, the data for the (+x, +y) and (+x, 0) cases were examined in detail. The location of each character in the two-dimensional space was determined, and separate plots were made showing the precise interstimulus intervals for the cases at each level of performance.

If low performance in the two critical categories were associated with a particular interstimulus interval (a possibility analogous to the spatial-adjacency rule), the low-performance cases should cluster within a confined region of the first quadrant of the two-dimensional space. Further, plots representing progressively higher performance should show progressively fewer cases within the region of the low-performance cluster. Of course, if a critical interstimulus interval is not associated with blanking, such a pattern would not be expected.

The plots revealed no evidence supporting a critical interstimulus interval; they did not show clustering. To illustrate the point, Figure 3 presents a composite plot, the data for instances at the extremes of the performance scale. There were 72 instances of very low performance (probability of correct report of 0.3 or less) and 56 cases of perfect performance in the two categories. Figure 3 shows the precise interstimulus

intervals for both performance groups. In addition, for the low-performance cases, the figure indicates the total-display time associated with each instance.

As is clear in the figure, high- and low-performance cases did not occupy different regions of the space. Further, instances with the same coordinates yielded performance at both extremes of performance. In short, by isolating blanking within the two categories, the two-dimensional space seems to describe the phenomenon in a gross way, but beyond the gross level, the data offer no support for attempts to describe it in terms of the exact timing of flanking items.

In summary, although the present data suggest that blanking is a metacontrast-type phenomenon, we have been unable to define exactly which properties of the various spatiotemporal presentation orders produce it. It is clear, however, that blanking is not an all-or-none phenomenon; the cumulative proportion curves do not show the changes of slope associated with a bimodal frequency distribution. Finally, the failure of the critical interstimulus interval idea indicates that more attention should be paid to the unique spatiotemporal features of particular presentation orders.

NOTES

1. In our notation, the digits refer to the time of arrival on the CRT (temporal position). The position of the digit in the string refers to the relative spatial location on the CRT. Thus, the string 31425 indicates a series of five successive displays. For the word CHAIR, the displays would be: -H---, ---I-, C---, ---A---, and ----R.

2. The rules are abstracted from Mayzner and Tresselt (1970, p 605). They note an important exception to their rules involving mixed-content displays. Because the present work involves only letter displays, the exception does not apply.

3. A variety of alternate predictions based on, for example, 100 ± 5 , . . . , 25 msec and 90 ± 5 , . . . , 25 msec were also considered. None were more successful than the 100 ± 20 msec rule.

4. In this connection, it is interesting to note the performance on the practice trials. Recall that the demonstration-practice trials used display parameters known to produce a strong blanking effect. Performance on "blanked" letters was approximately 28% and that on the nonblanking letters was about 86%.

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Figure 3. The 72 low-performance cases and the 56 perfect-performance cases in the (+x, +y) and (+x, 0) categories as a function of the interstimulus interval to the letter at the left and that to the letter at the right.