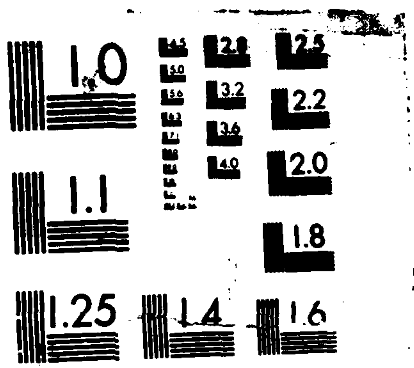
AD-A181 330 DIRECT ACCESS BY SPATIAL POSITION IN VISUAL MEMORY 1 1/1
SYNOPSIS OF PRINCIPAL FINDINGS(U) PENNSYLVANIA UNIV
PPHILADELPHIA S STERNBERG ET AL 20 JAN 86
UNCLASSIFIED N00014-85-K-0643 F/G 5/8 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

DTIC FILE COPY

AD-A181 330

DTIC ELECTE JUN 1 8 1987 D

REPORT DOCUMENTATION PAGE

1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY	3. DISTRIBUTION/AVAILABILITY OF REPORT: Approved for public release; Distribution Unlimited
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE	
4. PERFORMING ORGANIZATION REPORT NUMBER(S): Technical Report #1	5. MONITORING ORGANIZATION REPORT NUMBER(S)
6a. NAME OF PERFORMING ORGANIZATION: University of Pennsylvania; 6b. OFFICE SYMBOL (If applicable)	7a. NAME OF MONITORING ORGANIZATION: Personnel & Training Research Programs, Office Of Naval Research Code (Code 1142PT), 800 North Quincy Street
6c. ADDRESS (City, State, and ZIP Code): 3815 Walnut Street, Philadelphia, Pennsylvania 19104-6196	7b. ADDRESS (City, State, and ZIP Code): Arlington, Virginia 22217-5000
8a. NAME OF FUNDING/SPONSORING ORGANIZATION; 8b. OFFICE SYMBOL (If applicable)	9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00014-85-K-0643
8c. ADDRESS (City, State, and ZIP Code)	10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO
61153N	RR04204	RR04206-01	

11. TITLE (Include Security Classification)
Direct Access by Spatial Position in Visual Memory: 1. Synopsis of Principal Findings

12. PERSONAL AUTHOR(S)
Sternberg, Saul; Knoll, Ronald L.; (AT&T Bell Labs) Turock, David L. (AT&T Bell Labs)

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Technical Report	FROM 85Sept01 TO 87Aug31	1986 January 20	16

16. SUPPLEMENTARY NOTATION
Work Collaborative with AT&T Bell Laboratories

17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	Psychology; Visual-information-processing; reaction time; visual memory
05	10		

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

Changes in the internal representation of a visual display during the first second after presentation are among the earliest phases of human cognition where memory mechanisms may be investigated. The effect of array size (2-6 digits) on the latency to name a visually marked element in a brief display increases rapidly with marker delay, revealing such a change in representation. For early markers the effect is negligible, indicating direct access (and spatially-selective attention); for late markers the effect is a linear increase, indicating a failure of selective attention and suggesting search. In other words, the transformation changes the representation from a random-access memory (RAM) to a sequential-access memory (SAM). Two alternatives to direct access (marker makes element visually distinctive; marker automatically attracts visual attention) are rejected, as tactile spatial markers produce similar effects.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	21. ABSTRACT SECURITY CLASSIFICATION
22a. NAME OF RESPONSIBLE INDIVIDUAL: Dr. Harold Hawkins	22b. TELEPHONE (Include Area Code): 202-696-4323; 22c. OFFICE SYMBOL: ONR1142PT

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE

Direct Access by Spatial Position in Visual Memory: 1. Synopsis of Principal Findings

Saul Sternberg
University of Pennsylvania and AT&T Bell Laboratories

Ronald L. Knoll
AT&T Bell Laboratories

David L. Turock
AT&T Bell Laboratories
Murray Hill, New Jersey 07974

ABSTRACT

Changes in the internal representation of a visual display during the first second after presentation are among the earliest phases of human cognition where memory mechanisms may be investigated. The effect of array size (2-6 digits) on the latency to name a visually marked element in a brief display increases rapidly with marker delay, revealing such a change in representation. For early markers the effect is negligible, indicating direct access (and spatially-selective attention); for late markers the effect is a linear increase, indicating a failure of selective attention and suggesting search. Two alternatives to direct access (marker makes element visually distinctive; marker automatically attracts visual attention) are rejected, as tactile spatial markers produce similar effects.

Accesion For
NTIS CRA&I ☒
DTIC TAB ☐
Unannounced ☐
Justification ....

By ....
Distribution /

Availability Codes

Dist | Avail and / or Special
A-1

DTIC COPY INSPECTED 7

Reproduction in whole or part is permitted for any purpose of the United States Government.

Approved for public release; distribution unlimited.

Sponsored in part by the Personnel and Training Research Programs, Psychological Sciences Division, Office of Naval Research, under Contract No.N00014-85-K-0643, Contract Authority Identification Number NR 154-533/5-17-85.

87 6 16 034

January 20, 1986

Direct Access by Spatial Position in Visual Memory: 1. Synopsis of Principal Findings[1]

1. Introduction

In recent years the traditional account of the dynamics of short-term visual memory -- or iconic memory -- has come under attack. For example, Coltheart (1980, 1984) suggested that there may be two different representations concurrently present after a display, one that is phenomenally visible, and a different one from which information is extracted.[2]

What are the initial properties of the memory-representation of a display, and how do they change over time? Given Coltheart's suggestion, the question may even be raised whether the earliest representation from which information is extracted is a visual (or spatial) one. Indeed, what properties *ought* a representation have to be called visual (or spatial), given that it may not be phenomenally visible?

Direct access by spatial position is one candidate. We would argue that this property was implicitly assumed in the classic spatially-cued partial-report experiments of Sperling (1960) and of Averbach and Coriell (1961). Suppose this property obtains, and suppose further that we know how to specify, or address, a location in the memory. Then information about the element in the specified location should become available with approximately the same delay, regardless of the number of other filled locations. In the terms of Kahneman, Treisman & Burkell (1983), the "cost of visual filtering"[3] should be negligible. On the other hand, if (for example) the representation of the display took the form of covert sequential verbalization, there seems less reason to expect direct access by spatial position.

---

1. This memorandum approximates the verbatim text of a paper presented at the annual meeting of the Psychonomic Society, Boston, November 1985. The first series of experiments reported could not have been done without the expert hardware and software support of A. S. Coriell and W. J. Kropfl. The remaining experiments depended on the Parasite-FS real-time operating system developed by C. E. Wright and M. A. Derr in Bell Laboratories' Human Information-Processing Research Department. The work reported was supported in part by Contract N00014-85-K-0643 between the Office of Naval Research and the University of Pennsylvania.

2. Earlier, Turvey (1978, pp. 108-111) had reviewed several studies that indicated the existence of "nonvisible visual representations," and suggested that whereas the visible representation was referred to retinal coordinates, the longer-lasting nonvisible one was not.

3. The "cost of visual filtering" is the additional time required to select and respond to a specified display element that results from the process of rejecting or ignoring other display elements.

2. Experimental Method

We chose to address locations in memory in the same way that Averbach & Coriell did, with a *visual* marker that designated a *single* element. Indeed, our experiments were similar to theirs, but with several critical differences, mentioned below. A sample display from our first series of experiments is shown in Figure 1. It contains three constituents, which could appear and disappear at different times. One is the array of digits, here of size four. Another is a pair of dots for each digit ("registration dots"). And the third is the marker (or probe), two vertical line segments, one above and one below the target digit. The subject's task was to name the target digit as fast as possible; we measured vocal reaction time (RT). Subjects were paid for speed and penalized for errors. We varied array size from trial to trial, and probe delay from block to block.[4]

Three of the possible time sequences of array, registration dots, and marker are described in Figure 2. In all three examples, the correct response is to pronounce the word "eight." In the first example, probe delay is zero. The 50 msec probe and the 150 msec array turn on simultaneously. In the second example the probe immediately follows the array, so the probe delay is 150 msec. The final example shows a long delay. Here the dots are especially useful in reducing difficulties of registration of array and marker. The dots stayed on until the response.

There are three important differences between our experiments and those of Averbach and Coriell (1961). First, rather than overloading the memory we used small arrays, so that subjects were almost always correct. The average error rate was about 3%.[5] Second, we applied time pressure, and the primary measure was reaction time. Finally, we varied the number of elements in the array, since our main interest is in the effect of array size on mean reaction time.

Some of the details of design and procedure are best considered in the context of Figure 3. The display area contained six potential element locations *(absolute positions)*. At the start of a trial, subjects fixated in the center of this area.[6] To avoid confounding number of elements *(array size)* with their separation, we placed elements in *contiguous* locations. To reduce the confounding of array size with retinal eccentricity, we placed the arrays at all possible positions within

---

4. In the first series of experiments (Experiments 1-5, Section 3) array size was $s=3,4,5$, or 6, and probe delay (in msec) was -50, 0, 150, 350, 650, 950, 1650, or 3450.

5. The effects of array size and probe delay on error rate were similar to their effects on RT; details will be included in a subsequent report.

6. A change with delay in the effect of absolute position suggests that at long probe delays subjects may have shifted their fixation from the center of the display area to the center of the array.

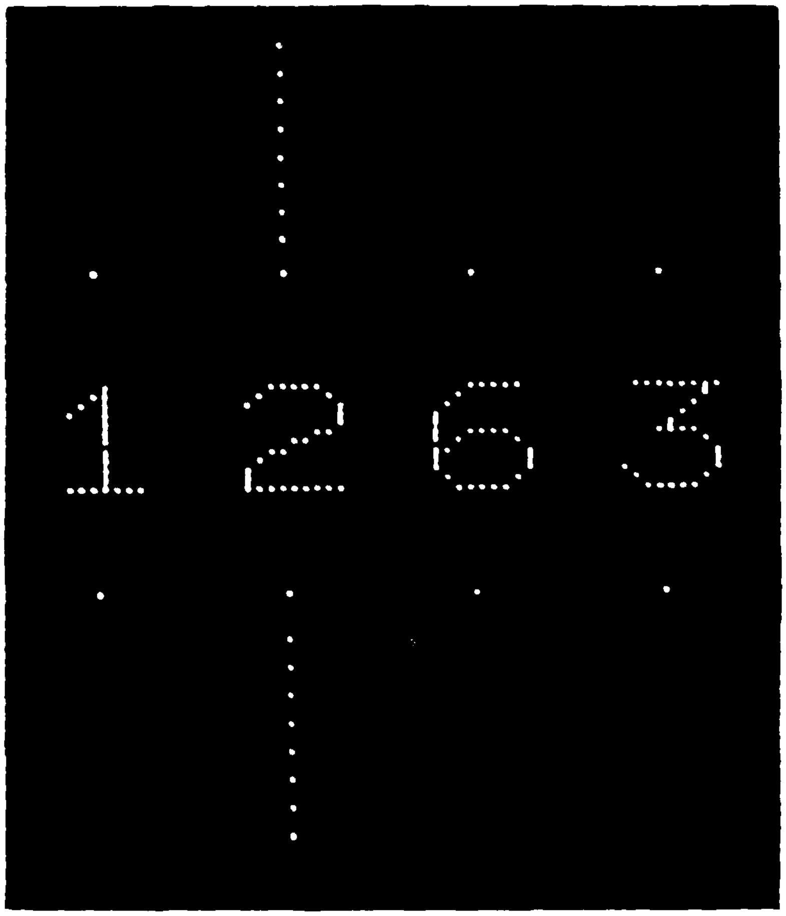


Figure 1

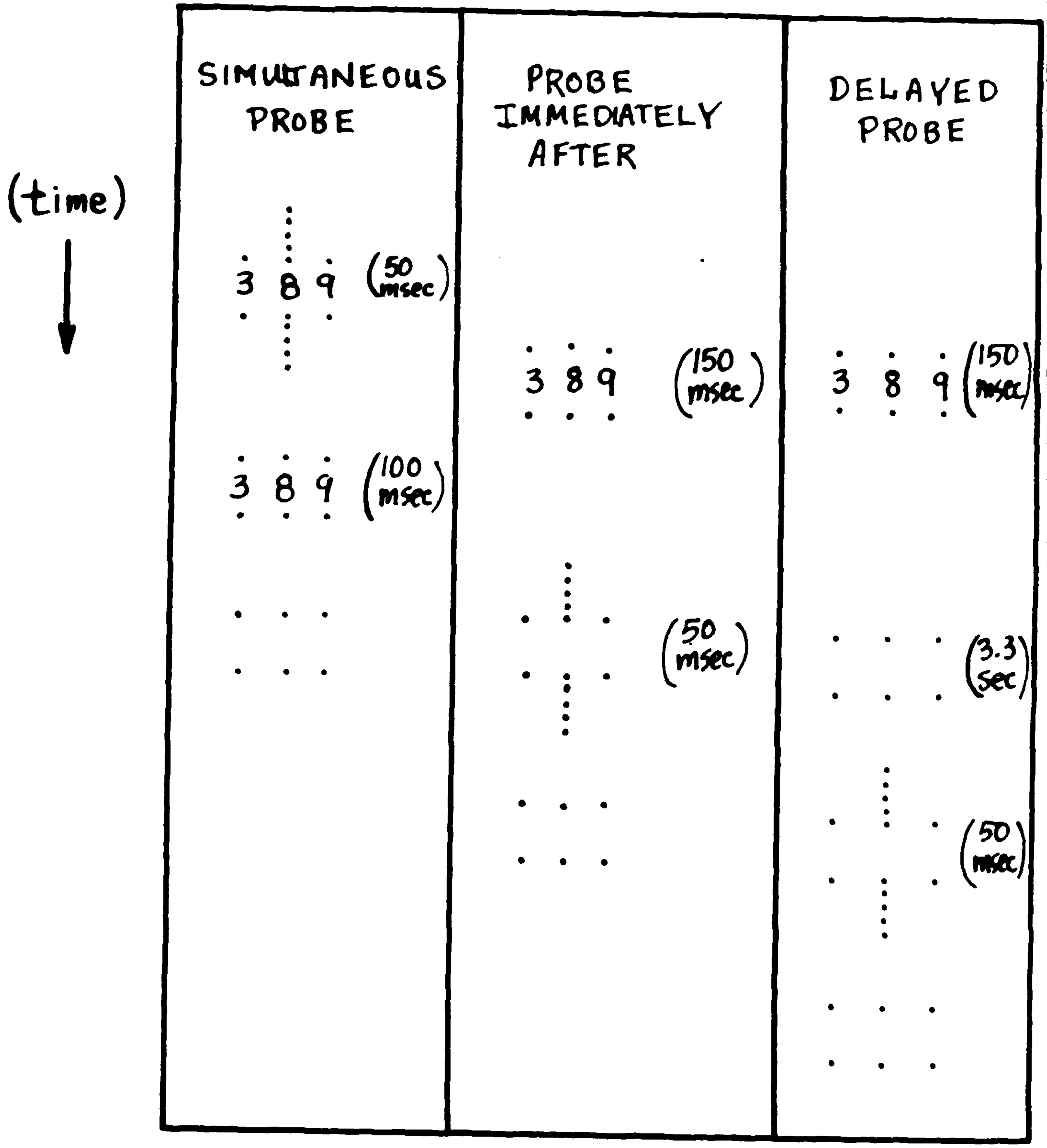

(time)
SIMULTANEOUS PROBE
3 8 9 (50 msec)
3 8 9 (100 msec)
PROBE IMMEDIATELY AFTER
3 8 9 (150 msec)
(50 msec)
DELAYED PROBE
3 8 9 (150 msec)
(3.3 sec)
(50 msec)

Figure 2

the display area.[7]

There are of course several factors other than array size that might influence reaction time: for example, absolute positions of array and of marker (and target element) within the display area, and serial (relative) position of the target element within the array. It is not possible to arrange for all these factors, together with array size, to be mutually orthogonal. The obvious simple averaging we performed is biased, and happens to favor the smaller arrays.[8] As shown below, however, a more sophisticated multiple regression analysis, in which the position effects are estimated and removed, suggests that the simple analysis is not far off. At this writing, however, only some of the data have been treated this way.[9]

3. Results with Visual Markers

Data from our first series of experiments, averaged over the four subjects, are shown in Figures 4 (shorter delays) and 5 (longer delays). Before starting this series, each subject had served for 28 hours in a related task.[10] The new series included about 26 hours of testing. Each plot shows mean reaction time as a function of array size. In each of Experiments 1-5 we tested several probe delays in a balanced order. The time lines at the top of both figures show that probe delays start at -.05 sec (or -50 msec) on the left, and become positive on the right. Each experiment is represented by the plots in one row, and each probe delay is shown in a different column.

---

7. The leftmost element in an array of size $s=4$, for example, could occupy absolute positions 1, 2, or 3.

8. For an array of size s, each of the $7-s$ possible array positions occurred equally often, as did each of the s possible serial positions of the target element. An equally-weighted mean over the $(7-s)s$ resulting combinations produces a distribution of absolute positions that varies with array size. (The frequencies of markers over the six possible absolute positions are in proportion to (1:2:3:3:2:1) for $s = 3$ and 4, to (1:2:2:2:2:1) for $s = 5$, and to (1:1:1:1:1:1) for $s = 6$. The resulting mean distance from fixation point to marker (mean eccentricity), measured in absolute-position units, was 1.17, 1.17, 1.30, and 1.50 for $s = 3$, 4, 5, and 6, respectively. Because RT tends to be longer with greater eccentricity, smaller arrays are favored. Unless these effects are removed, mean RT might then artifactually appear to increase with array size.
   The smaller arrays are also favored by the distribution of serial positions, because end positions tend to produce shorter RTs, and the proportion of end positions ($2/s$) decreases with s. Whether this last effect should be removed, however, in estimating a "pure" effect of array size, may depend on whether it is interpreted as an effect of lateral masking on acuity, or an effect of the order of a self-terminating search, for example.

9. In the multiple linear regression analysis we separately fitted an additive model to the data for each probe delay and each subject. We incorporated effects of array size, response digit, and serial position, as well as two separate effects of absolute position, one for end elements (serial positions 1, s), and the other for interior elements.

10. See Sternberg, Knoll, & Leuin, 1975.

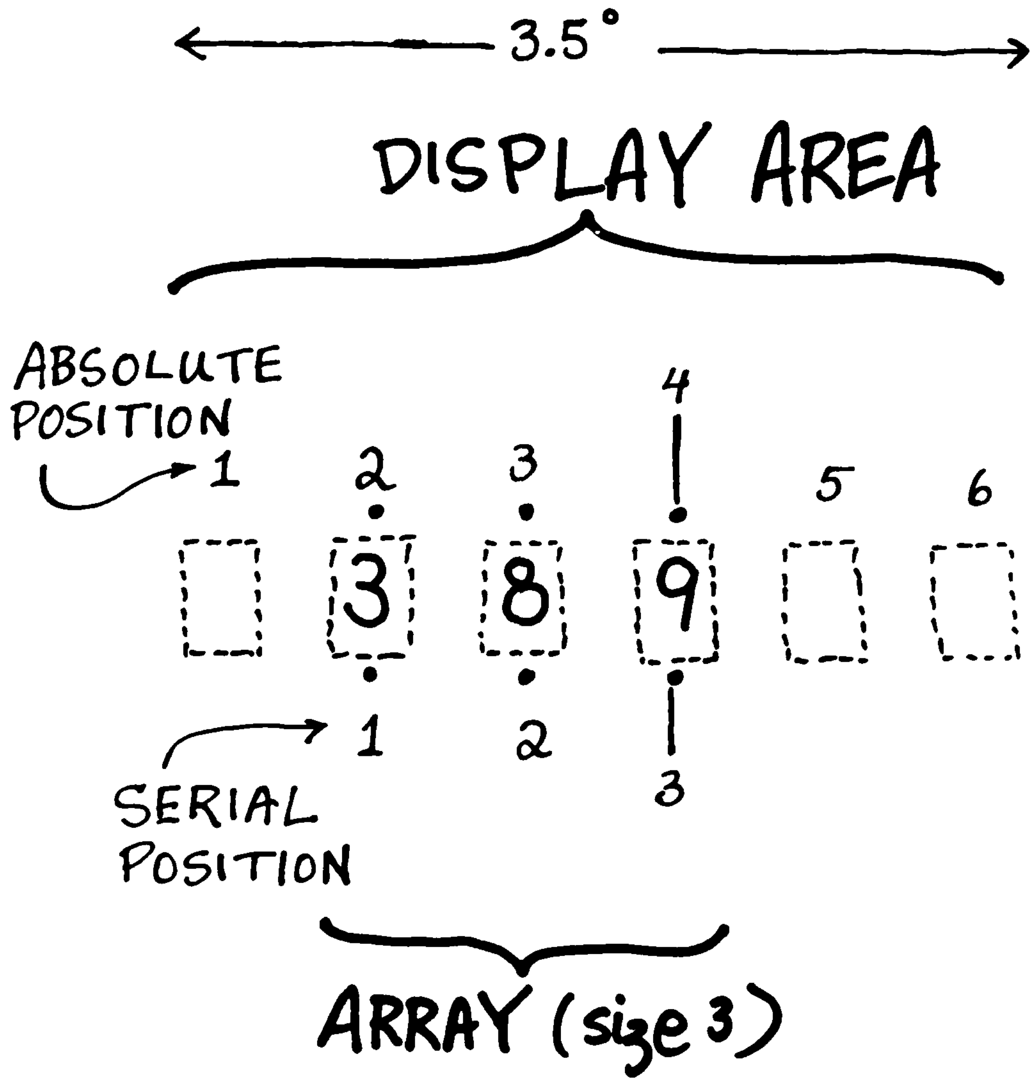

3.5°
DISPLAY AREA
ABSOLUTE POSITION
1
2
3
4
5
6
3
8
9
1
2
3
SERIAL POSITION
ARRAY (size 3)

Figure 3

At all delays the lines fit well, justifying a description of the data in terms of slope and intercept. Functions from the same probe delay in different experiments show good agreement, especially in their slopes.[11] Consider first the data in Figure 4. For the earliest probes the effect of array size is negligible. This is evidence for the direct-access property. Even after a short delay an effect emerges, however. That is, the direct-access property appears to be rapidly lost. Put another way, the cost of visual filtering (Kahneman, et al., 1983) is highly sensitive to timing.[12]

The plots for longer delays (Figure 5) show that by about 2/3 second the effect of array size has reached an asymptote: There is little further change, even out to 3.5 seconds. We shall argue that the dramatic change with delay in the pattern of retrieval times reflects a qualitative transformation of the memory representation of the array -- a change that is completed in less than one second. One approach to testing its completeness is to see whether the pattern after 2/3 second shows any evidence of the display having been visual. This was the purpose of Experiment 6. We displayed the registration dots on an otherwise blank screen, while the subject *heard* the digits as a spoken sequence. The subject had been told to use the natural correspondence between serial-order (of the spoken digits) and left-to-right position (of the registration dots). After about two seconds the visual marker appeared. Results are shown in the lower right corner of Figure 5. The data are similar to those for a visual array after less than a second.

Figure 6 shows the slopes of the fitted lines separately for the six experiments, as a function of probe delay.[13] The agreement across experiments is good, with the effect of array size growing from close to zero to about 80 msec per digit in less than a second.

In Figure 7, slope values have been combined across experiments, and are shown along with the corresponding intercepts, as functions of probe delay. The bars indicate estimates of two standard errors, based on differences among subjects. While the slope rises, the intercept falls, and with a similar time course. We mentioned (Section 2) that a more sophisticated analysis using multiple

---

11. The heights of the functions (reflected by the intercepts) decrease slightly with experiment number, as the subjects become increasingly practiced.

12. Because the dependence of "cost" on timing is so great, it is not useful to make statements about cost without also stating the effective time-point in the life of the display memory at which the location of the target is specified. Furthermore, this time point is not necessarily zero just because marker and array are displayed simultaneously, and is likely to be greater than zero, given simultaneity, when some visual or categorical aspect of the display elements that must be discriminated informs the subject about target location.

13. Note that for Experiment 6, where no array was displayed and the sequence of spoken digit names was presented at a rate of 510 msec/digit, we cannot define an equivalent probe delay.

regression produces a better measure of the array-size effect. The slope bias in our simpler analysis seems to be only about 5 msec, however. For example, the improved slope estimate for the -50 msec probe delay is 0.7 ± 1.0 msec/digit, whereas the value given by the simple analysis (and shown in Figure 7) is 4.7 ± 1.6 msec/digit.

4. Interpretation: Rapid Transformation of Visual Memory

It is tempting to argue from these data that there is no persistence of the direct-access property. But note that this argument depends on making the unwarranted assumption that the *effective* probe delay is equal to the *physical* probe delay.[14]

The slope reflects operations that are influenced by array size, whereas the intercept reflects operations that are not so influenced. Figure 7 shows that probe delay affects both sets of operations, and with a similar time course. This similarity suggests a common mechanism.

One interpretation is as follows: The initial representation of the array, which has the direct-access property, is transformed into something else in less than a second, with rapid loss of direct access. At any delay, once the representation of the probed element is found, (either directly, or by search) it is converted into its spoken name. The intercept drops because the duration of this conversion operation is shortened with delay. The similarity in time course follows from the fact that the same transformation that destroys the direct-access property also brings the array elements closer to their spoken names.[15]

---

14. It seems likely that the effective probe delay is greater than the physical delay, because the time to transmit information about the marker from the retina to the relevant place(s) in the visual system plus the time to discriminate its location is greater than the time to transmit information about the array from the retina to relevant place(s) in the visual system. If so, then the delay of -50 msec may effectively be greater than zero. One potential complication is that if a difference between effective and physical delays existed, it might vary with physical delay, so that to provide a function relating slope to effective delay, the delay axis would have to be more than merely translated.

15. For other evidence that indicates such a transformation, derived from three other experimental approaches using reaction-time measurements with small arrays, see Sternberg, Knoll, & Leuin, 1975; Sternberg & Knoll, 1985, and Turock, 1985.

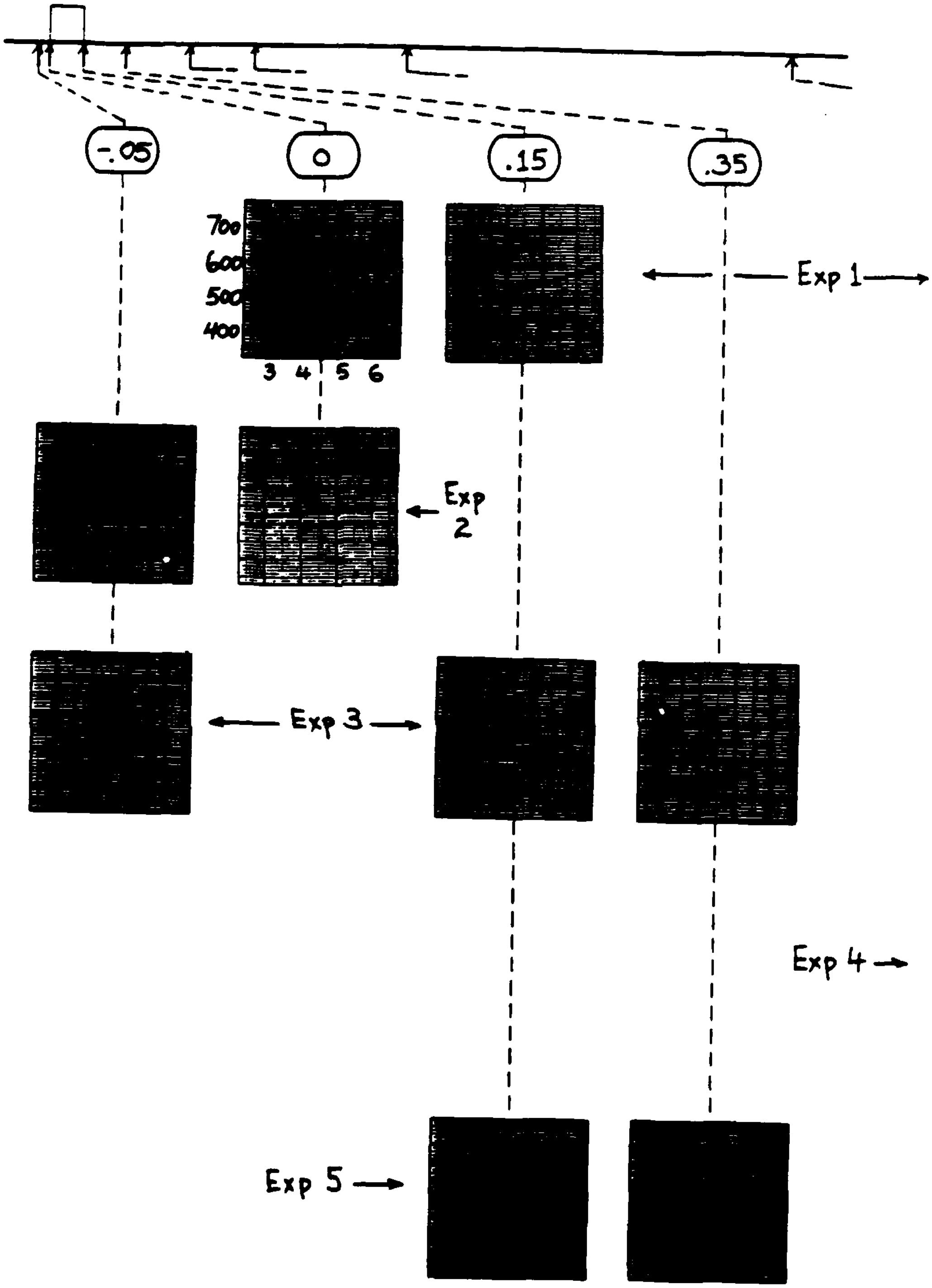


Figure 4

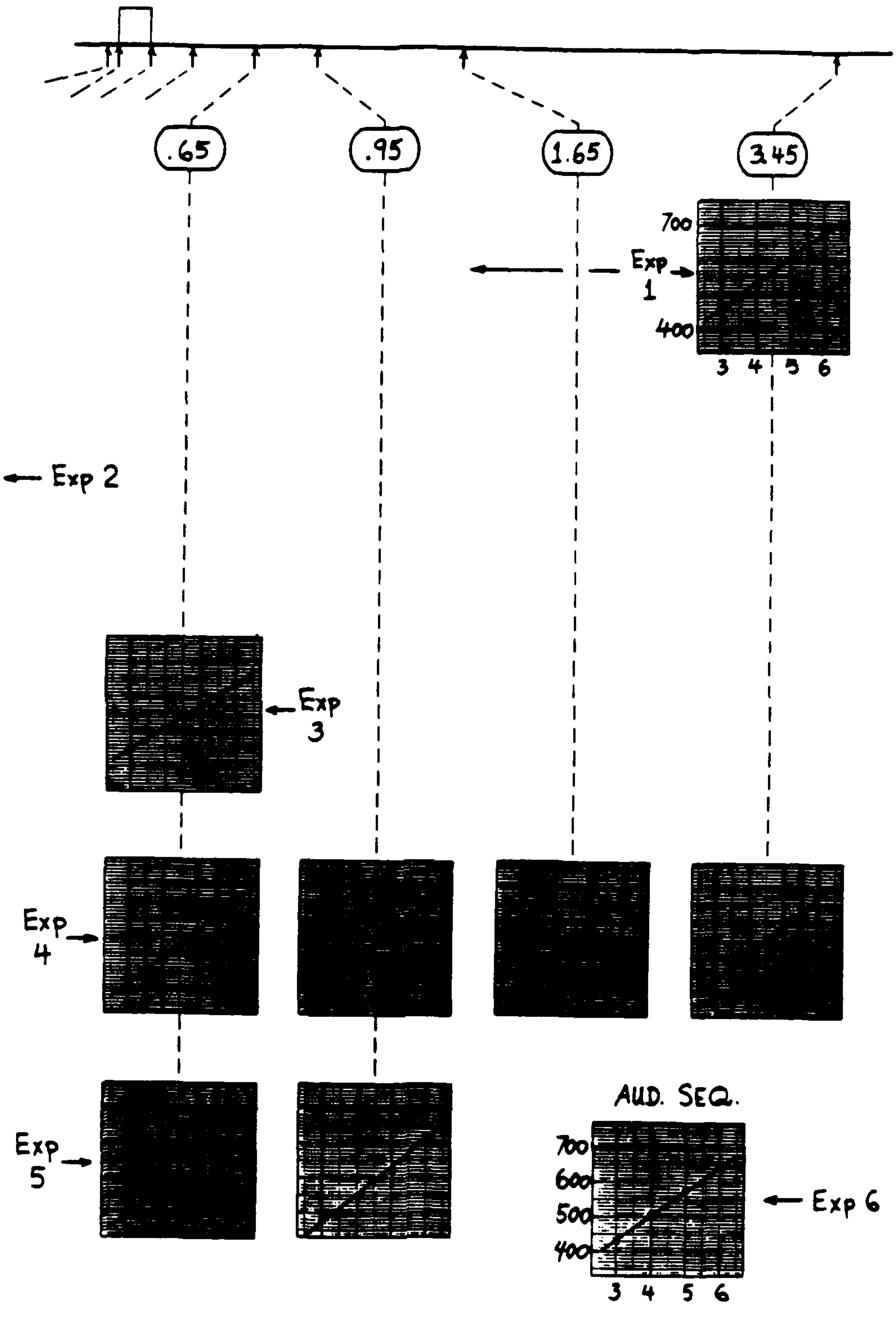

.65
.95
1.65
3.45
700
Exp 1
400
3 4 5 6
← Exp 2
Exp 3
Exp 4
Exp 5
AUD. SEQ.
700
600
500
400
3 4 5 6
← Exp 6

Figure 5

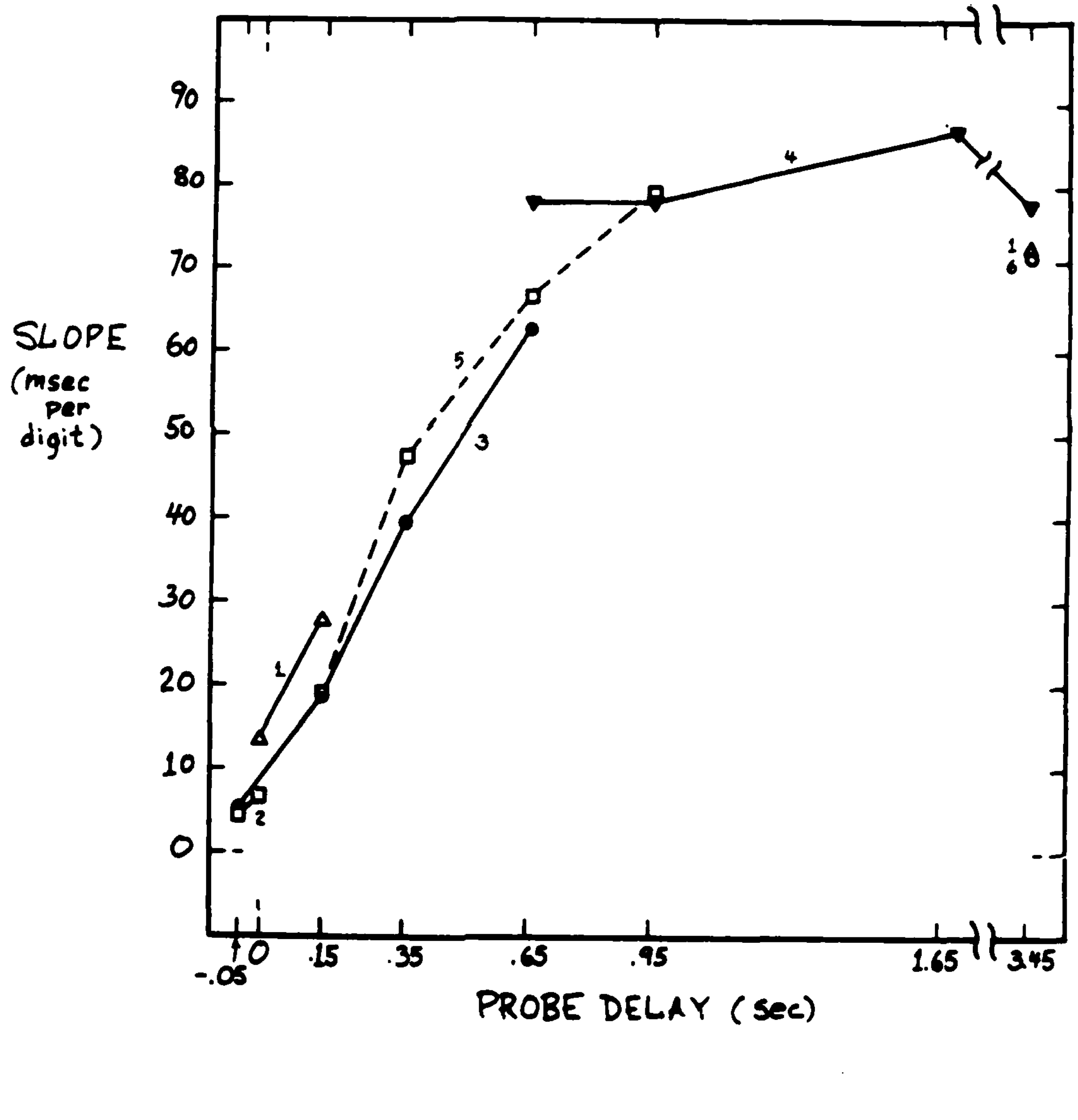
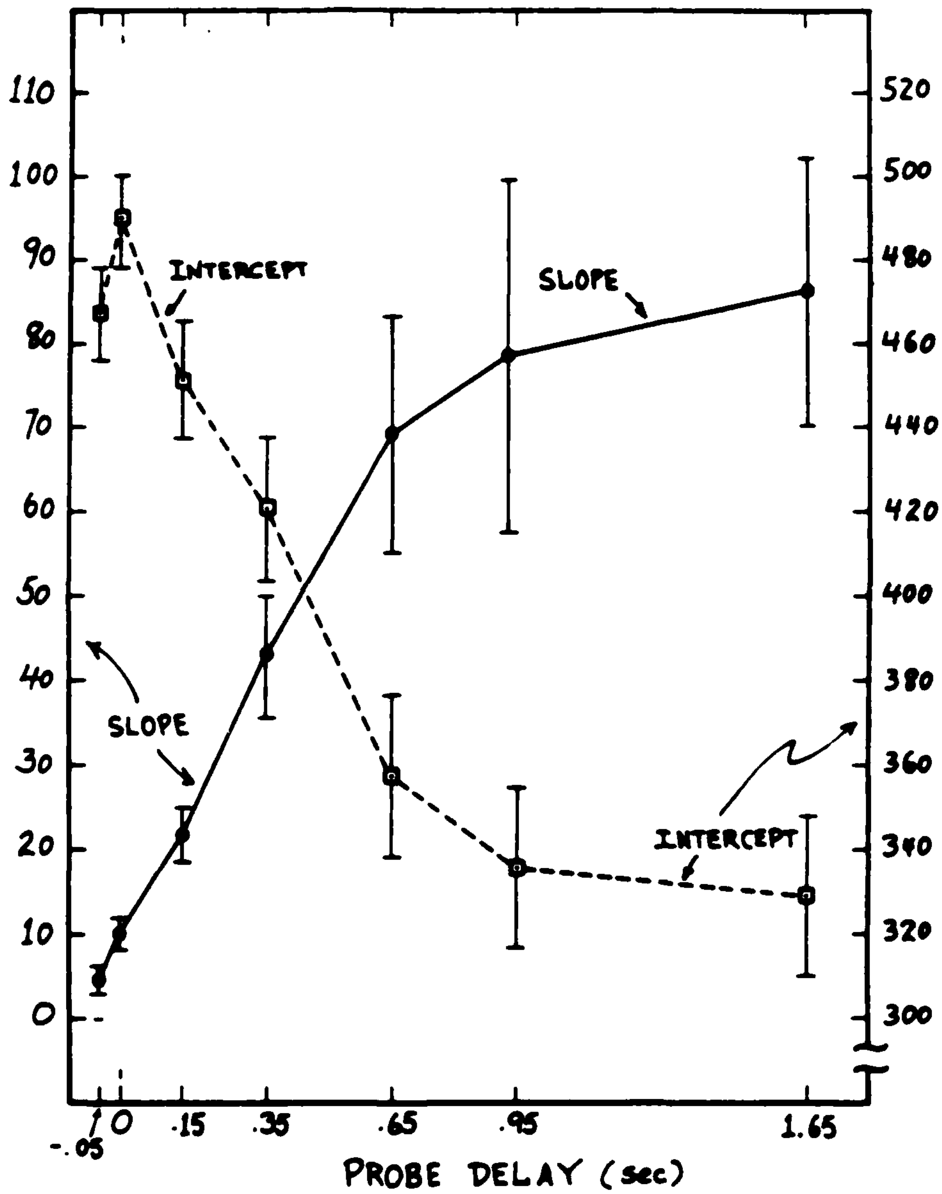

SLOPE
(msec per digit)
90
80
70
60
50
40
30
20
10
0
-.05
0
.15
.35
.65
.95
1.65
3.45
PROBE DELAY (sec)
1
2
3
4
5
6

Figure 6



110
100
90
80
70
60
50
40
30
20
10
0
520
500
480
460
440
420
400
380
360
340
320
300
INTERCEPT
SLOPE
SLOPE
INTERCEPT
-.05
0
.15
.35
.65
.95
1.65
PROBE DELAY (sec)

Figure 7

5. Alternative Explanations for the Absence of an Array-Size Effect at Short Probe Delays

We have discussed two principal findings about the effect of array size. First, the effect is absent for early probes. And second, the effect is present for delayed probes. We have already mentioned one interpretation (direct access), but there are others. Consider first the finding for early probes. Figure 8 lists the three alternative explanations we have considered.

The first was suggested by Julian Hochberg.[16] Given approximate synchrony of probe and array, the marker is visually integrated with the target digit. This produces a highly distinctive pattern, easily found by a search process. Thus we find no array-size effect, not because search is unnecessary, but because the set of elements searched (i.e. the set of distinctive patterns made up of digit plus marker) is always of size one.

The second alternative is suggested by results of Yantis and Jonides (1984). Instead of merely informing the subject of a location, the marker automatically attracts visual attention to that location. A search for the marked location thus starts at its goal point, and, if the target element appears in close temporal proximity to the marker, finds it in the first location searched. Thus, we find no array-size effect, not because search is unnecessary, but because the *order* of the (self-terminating) search places the target element first.

6. Experimental Test of the Alternatives

Both of the explanations above depend on the marker being visual. To test them we compared visual and tactile markers with a new set of six subjects in Experiment 7. We used a 50 msec vibration of a fingertip as the tactile marker (see Figure 9), and taught subjects a correspondence between six fingers and the six display locations.[17] To help, we incorporated schematic fingers in the displays. (See Figure 10, which contains the sequence of displays on a sample trial.) In some trial blocks the marker was visual, as shown, and in others, tactile. Because of improved equipment, we were able to reduce array duration to 50 msec in this experiment. Subjects had 14 hours of practice, mainly to learn the tactile-visual correspondence, followed by 22 hours of testing.[18]

---

16. Personal communication.
17. We used the index, middle, and little finger on each hand; preliminary testing suggested that discriminability was better with this combination than with three adjacent fingers on each hand.
18. We used array sizes of $s = 2, 3, 4, 5$, and 6, and probe delays (in msec) of -350, -150, -50, 150, 350, and 650.

Approximate Invariance of RT with Array Size for Leading and Simultaneous Probes

Some Alternative Explanations:

1. *Marker-target integration.* Appropriately timed visual marker is integrated with target element, making it distinctive; search is then fast (Hochberg).

2. *Shift of visual attention.* Abrupt visual marker automatically attracts visual attention and search starts at marked location (Yantis-Jonides), finding target if timing is appropriate.

3. *Direct access* by spatial position when memory is sufficiently young.

Figure 8

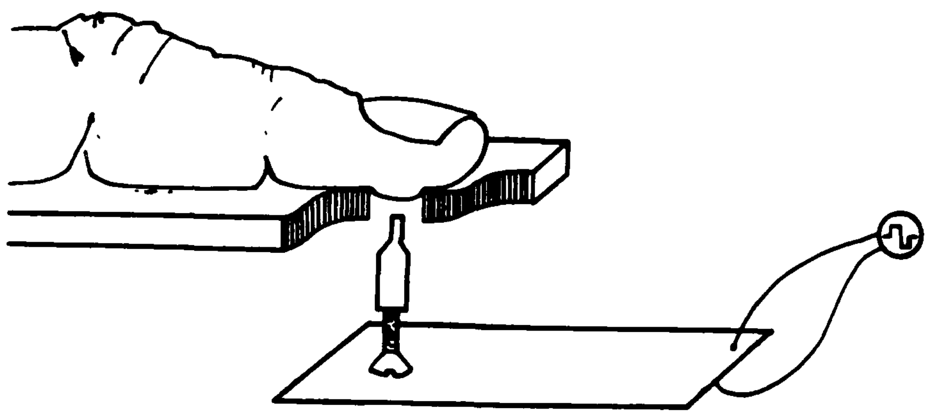


Figure 9

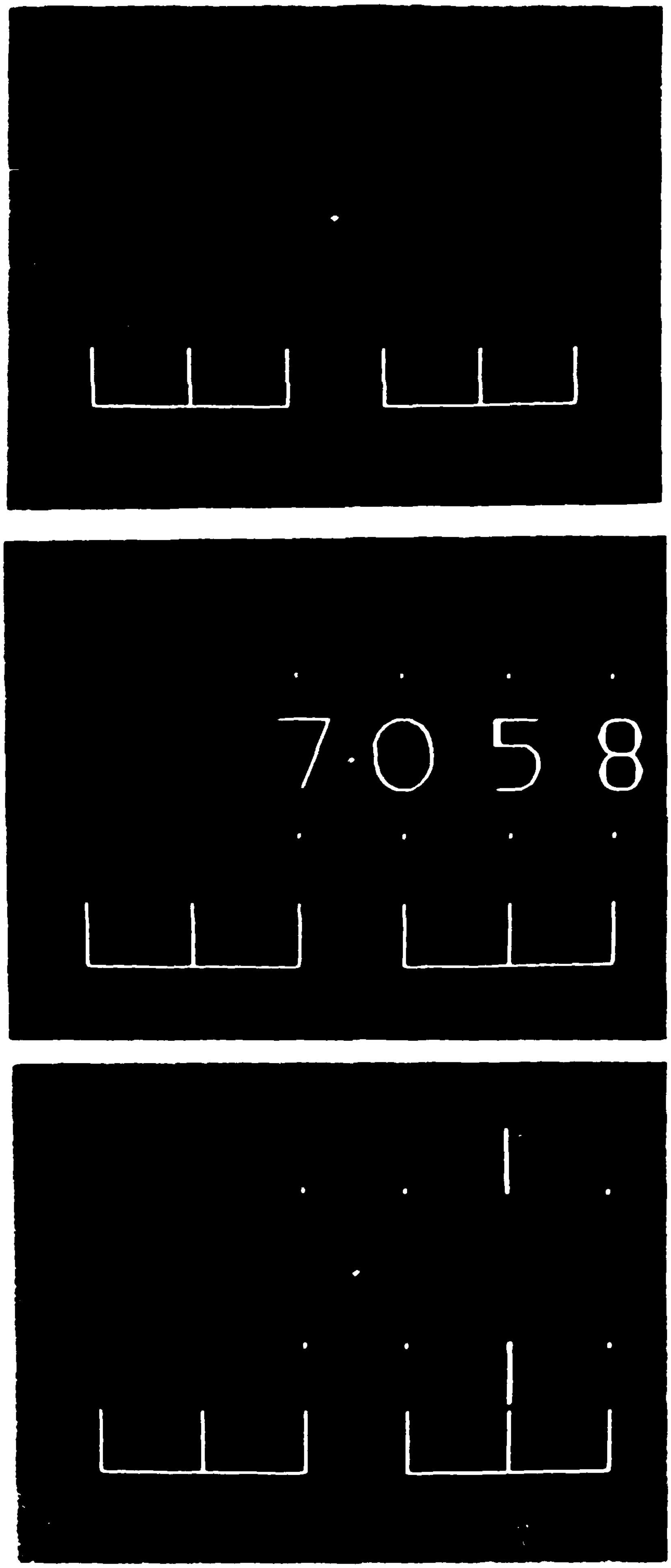


Figure 10

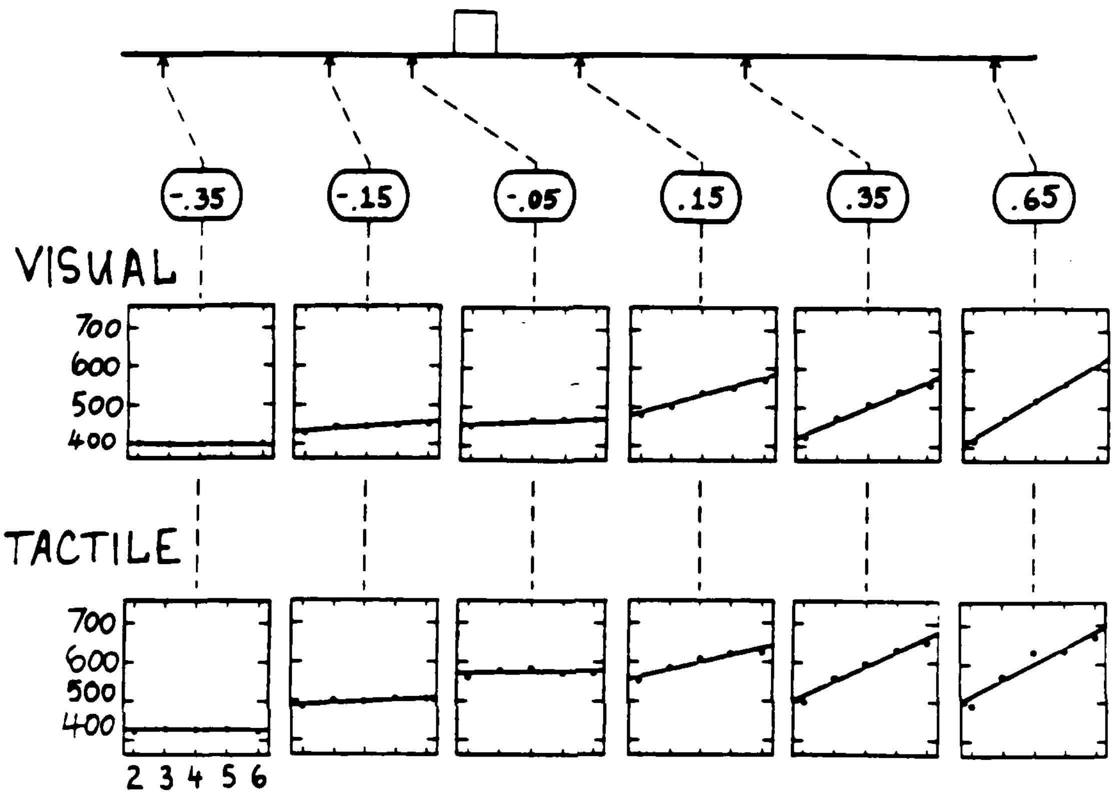

-.35
-.15
-.05
.15
.35
.65
VISUAL
700
600
500
400
TACTILE
700
600
500
400
2 3 4 5 6

Figure 11

Functions relating mean reaction time to array size at each of the six delays and for each of the two probe modalities are shown in Figure 11. The tactile data are somewhat less orderly than the visual, but slopes of the fitted lines agree well across modalities.[19] These plotted values are based on the more sophisticated (regression) analysis.

Among other things, these data demonstrate how misleading it may be to study arrays of only one size. Consider the effects of increasing positive probe delays: Delaying the probe shortens RT for small arrays while lengthening RT for large arrays.

Slopes of the twelve reaction-time functions from Experiment 7 are shown in Figure 12. Agreement between modalities is good. For both modalities, probes that just precede the array produce a negligible effect of array size.[20] For comparison, Figure 13 shows slopes from the earlier experiments on a similar plot.[21] Tactile markers convey information, but they are unlikely to add visual distinctiveness to a numeral, nor automatically cause a shift of visual attention. To explain performance with early markers we are left with the direct-access property.

7. Tests of Three Alternative Explanations for the Presence of an Array-Size Effect at Long Probe Delays

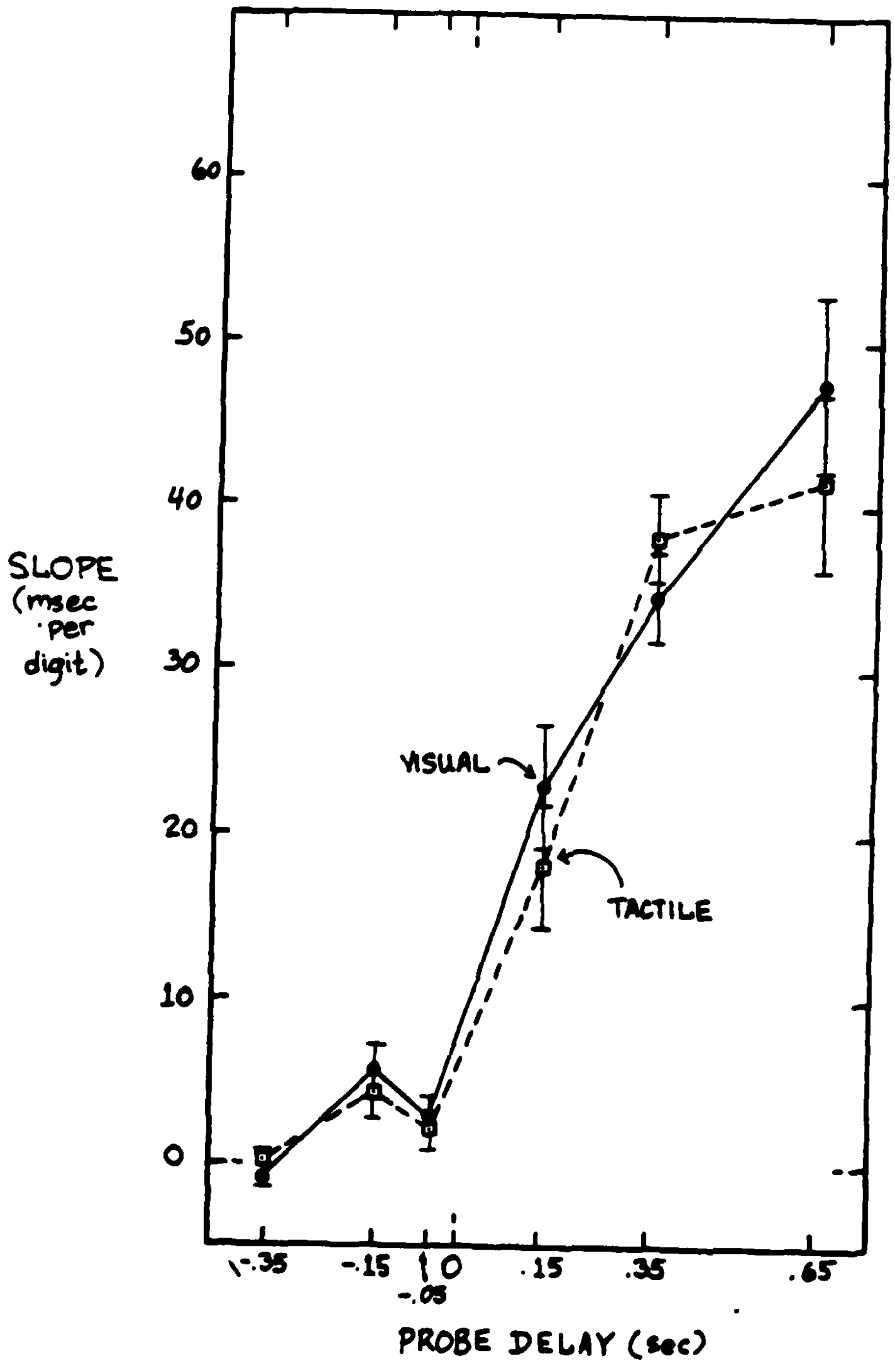
The second finding to be explained is the rapid emergence of an array-size effect as the probe is delayed. Does this necessarily mean a rapid loss of the direct-access property? Figure 14 lists the four explanations we have considered.

---

19. We added the new early delays to insure that we would cover the range of rapid change for both modalities. To our surprise it proved unnecessary to adjust the tactile probe delays relative to the visual, even though greater intercept values for the tactile markers suggest slower discrimination.

20. With a probe delay of -350 msec it seems likely that subjects had time between marker and array to shift their fixation from the center of the display area to the marked location; that subjects did this tends to be supported by data on the effect of absolute position. Given such a shift in eye position, which guarantees foveation of the target element, the retrieval mechanism may be fundamentally different. The slight increase in slope at -150 msec (relative to -350 msec and -50 msec) is reliable; it may indicate an array-preprocessing operation whose duration increases with array size. Such an operation might be reflected in the RT only when the marker leads the array appropriately: Delaying the marker slightly could cause the preprocessing operation to be "masked" by an overlapping process of discriminating the marker; With additional delay of the marker the preprocessing operation could be completed before the RT clock started.

21. These values were derived from the multiple-regression analysis applied to data from Experiments 3, 4, and 5.



60
50
40
30
20
10
0
SLOPE (msec per digit)
VISUAL
TACTILE
-.35
-.15
0
-.05
.15
.35
.65
PROBE DELAY (sec)

Figure 12

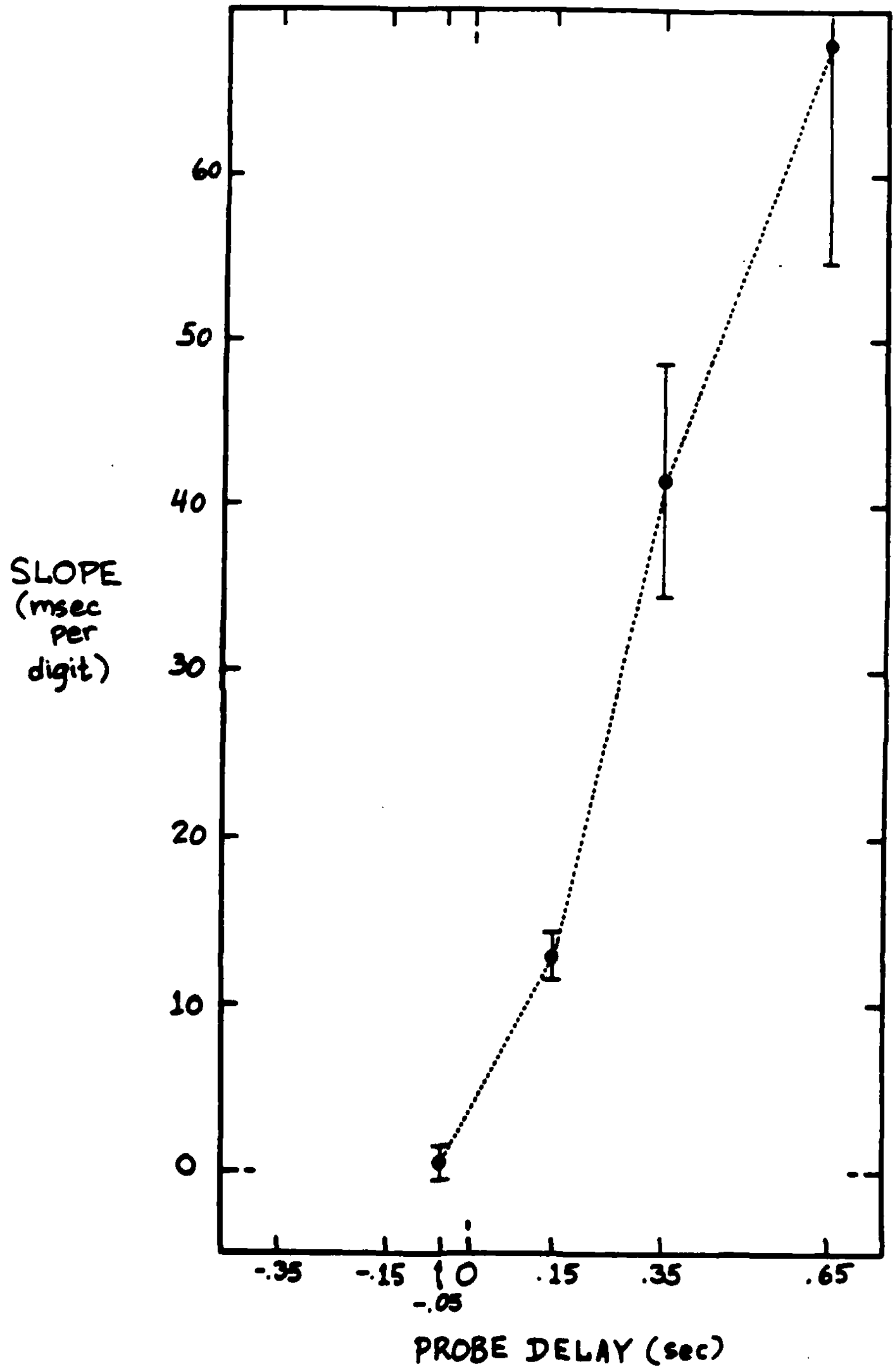

SLOPE (msec per digit)
0
10
20
30
40
50
60
-.35
-.15
-.05
0
.15
.35
.65
PROBE DELAY (sec)

Figure 13

7.1 Spatial Uncertainty

For the first alternative we begin with the observation that it takes time for a subject to discriminate the location of the marker. This discrimination time may be shorter when the location of the marker is less uncertain. Suppose the array is small. Then while the subject awaits a delayed probe she learns where the array elements are, and hence where the marker might be. This reduction with delay in spatial uncertainty would favor small arrays (especially if visual attention could be concentrated in the region outlined by the registration dots). Thus we might observe an array-size effect even while the direct-access property persisted, because of an indirect effect of array size on the time to discriminate the marker.

To test this possibility we used a -50 msec marker in Experiment 8, but displayed the registration dots 2/3 second in advance, to reduce spatial uncertainty (more for smaller arrays) by marking the set of locations to be occupied by the forthcoming array. The effect of array size was still negligible.

7.2 Response uncertainty

For the second alternative explanation, we begin by noting that the time to organize and execute a response from a small set of alternatives may be shorter than from a larger set.[22] If the subject identifies the array elements while awaiting a delayed probe, then smaller arrays are favored with smaller response sets. If this altered the duration of response operations, we would obtain an array-size effect. To test this possibility we used an early marker in Experiment 9, but specified the response set in advance, by sequentially displaying the array digits in a random order at one location and requiring subjects to name them aloud as they were displayed.[23] The effect of array size was still negligible.

7.3 Memory load

According to the third alternative explanation, as the subject awaits a delayed marker she identifies the array elements and stores them in working memory. The resulting memory load is greater for larger arrays. This load slows

---

22. For the naming of *displayed* numerals this effect has been found to be very small, although systematic. (See, e.g., Experiment 5 in Sternberg, 1969; note that the small effect reported of number of stimulus-response alternatives *combines* effects on stimulus-processing and response-organizing operations.) Under the conditions being considered here, however, the numeral is not displayed at the time the response is required.

23. This procedure also mimicked any possible contribution to the array-size effect with delayed probes of differential priming across array sizes of the encoding of the numeral to be named -- priming that might result from the subject's encoding of the array numerals while she awaited the probe. See Eichelman (1970), Proctor (1981), and Walker (1978), for example, on such priming effects.

Effect of Array Size (*s*) on RT for Delayed Probe

Some Alternative Explanations:

1. Reduction of *spatial uncertainty* of forthcoming marker, as positions of array elements are registered, favors small *s*.

2. Reduction of *response uncertainty*, as array elements are identified, favors small *s*.

3. As array elements are identified a *memory load* develops that slows other processes. (Load increases with *s*.)

4. *Loss of direct-access* property as memory ages.

Figure 14

the naming response and produces an effect of array size (because load size equals array size), even though the direct-access property persists. One of the necessary conditions for this alternative is that a memory load should slow the naming response to a marker.[24] In an attempt to reject this possibility we imposed an auxiliary memory load of varying size on the subject in Experiment 10 before presenting an array with an early marker.[25] To our dismay, we obtained a load effect. It was smaller than the normal array-size effect with a delayed probe, but substantial, nonetheless. More experimental clarification is needed.[26] For the present, we are forced to admit that our favored explanation of the emergence of an array-size effect -- the last one in Figure 14 -- may therefore be invalid. The direct-access property may persist for a time, but be camouflaged by something else.[27]

---

24. The other necessary condition is that the array does indeed generate a load on working memory.

25. We imposed the load by presenting a spoken sequence of digits. We attempted to induce the subject to actively maintain the load by then presenting a spoken test digit from the list, instead of the marker, on some trials. The correct response on those trials was to pronounce the name of the digit in the list that had followed the test digit, under time pressure. (See Sternberg, 1967, for results from this procedure using visual presentation of sequence and test digit.)

26. It should be emphasized that the discovery of a load effect does not, by itself, validate the third alternative explanation; it must also be shown that such a load is in fact generated during the long probe delays in the normal task.

27. If the direct-access property is in fact rapidly lost, it is worth considering why. One possibility is that the initial representation is referred to retinal coordinates, but that it changes rapidly into a representation that is referred to more abstract non-retinal spatial coordinates, thereby causing the marker-array mapping to change from "direct" to "indirect".(Turvey, 1978, p. 111, suggested that an initial short-lived representation is probably tied to retinal coordinates.) The similarity of our findings for tactile and visual markers seems to argue strongly against this idea as an explanation of the direct-access property and its possible rapid elimination, because the mapping from tactile marker to visual array would have to be "indirect" at all delays.

References

Averbach, E., & Coriell, A. S. (1961)
Short-term memory in vision.
Unpublished manuscript.

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

Coltheart, M. (1984)
Sensory memory.
In H. Bouma & D. Bouwhuis (Eds.), *Attention & Performance X*, Hillsdale, N. J.: Lawrence Erlbaum Associates, 259-285.

Eichelman, W. H. (1970)
Stimulus and response repetition effects for naming letters at two response-stimulus intervals.
Perception & Psychophysics, *7*, 94-96.

Kahneman, D., Treisman, A., & Burkell, J. (1983)
The cost of visual filtering.
Journal of Experimental Psychology: Human Perception and Performance, *9*, 510-522.

Proctor, R. W. (1981)
A unified theory for matching-task phenomena.
Psychological Review, *88*, 291-326.

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

Sternberg, S. (1967)
Retrieval of contextual information from memory.
Psychonomic Science, *8*, 55-56.

Sternberg, S. (1969)
The discovery of processing stages: Extensions of Donders' method.
In W. G. Koster (Ed.), *Attention and Performance II*, Acta Psychologica, *30*, 276-315.

Sternberg, S. & Knoll, R. L. (1985)
Transformation of visual memory revealed by latency of rapid report.
Unpublished manuscript.

Sternberg, S., Knoll, R. L., & Leuin, T. C. (1975)
Existence and transformation of iconic memory revealed by search rates.
Unpublished manuscript.

Turock, D. L. (1985)
A new technique for measuring transformations of visual memory.
Unpublished manuscript.

Turvey, M. T. (1978)
Visual processing and short-term memory.
In W. K. Estes (Ed.), *Handbook of learning and cognitive processes, Volume 5: Human information processing*. Hillsdale, N. J.: Lawrence Erlbaum Associates, 91-142.

Walker, P. (1978)
Short-term visual memory: The importance of the spatial and temporal separation of successive stimuli.
Quarterly Journal of Experimental Psychology, *30*, 665-679.

Yantis, S. & Jonides, J. (1984)
Abrupt onsets and selective attention: evidence from visual search.
Journal of Experimental Psychology: Human Perception and Performance, *10*, 601-621.

Dr. Phillip L. Ackerman
University of Minnesota
Department of Psychology
Minneapolis, MN 55455

Air Force Human Resources Lab
AFHRL/MPD
Brooks AFB, TX 78235

AFOSR,
Life Sciences Directorate
Bolling Air Force Base
Washington, DC 20332

Dr. Robert Ahlers
Code N711
Human Factors Laboratory
NAVTRAEQUIPCEN
Orlando, FL 32813

Dr. James Anderson
Brown University
Center for Neural Science
Providence, RI 02912

Dr. Nancy S. Anderson
Department of Psychology
University of Maryland
College Park, MD 20742

Technical Director, ARI
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Alan Baddeley
Medical Research Council
Applied Psychology Unit
15 Chaucer Road
Cambridge CB2 2EF
ENGLAND

Dr. Jackson Beatty
Department of Psychology
University of California
Los Angeles, CA 90024

Dr. Alvah Bittner
Naval Biodynamics Laboratory
New Orleans, LA 70189

Dr. Gordon H. Bower
Department of Psychology
Stanford University
Stanford, CA 94306

Dr. Robert Breaux
Code N-095R
NAVTRAEQUIPCEN
Orlando, FL 32813

Maj. Hugh Burns
AFHRL/IDE
Lowry AFB, CO 80230-5000

Mr. Niels Busch-Jensen
Forsvarets Center for Lederskab
Christianshavns Voldgade 8
1424 Kobenhavn K
DENMARK

Dr. Gail Carpenter
Northeastern University
Department of Mathematics, 504LA
360 Huntington Avenue
Boston, MA 02115

Dr. Pat Carpenter
Carnegie-Mellon University
Department of Psychology
Pittsburgh, PA 15213

Mr. Raymond E. Christal
AFHRL/MOE
Brooks AFB, TX 78235

Professor Chu Tien-Chen
Mathematics Department
National Taiwan University
Taipei, TAIWAN

Dr. David E. Clement
Department of Psychology
University of South Carolina
Columbia, SC 29208

Dr. Charles Clifton
Tobin Hall
Department of Psychology
University of Mass.
Amherst, MA 01003

Chief of Naval Education
and Training Liaison Office
Air Force Human Resource Laboratory
Operations Training Division
Williams AFB, AZ 85224

Assist.Chief Staff Research, Dev.,
Test, Evaluation Naval Education and
Training Command (N-5)
NAS Pensacola, FL 32508

Dr. Michael Coles
University of Illinois
Department of Psychology
Champaign, IL 61820

Dr. John J. Collins
Director, Field Research
Office, Orlando
NPRDC Liaison Officer
NTSC Orlando, FL 32813

Dr. Leon Cooper
Brown University
Center for Neural Science
Providence, RI 02912

Dr. Lynn A. Cooper
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15213

Capt. Jorge Correia Jesuino
Marinha-7A Reparticao
Direccao De Servico Do Pessoal
Praca Do Comercio
Lisboa, PORTUGAL

M.C.S. Louis Crocq
Secretariat General de la
Defense Nationale
51 Boulevard de Latour-Maubourg
75007 Paris, FRANCE

Dr. Hans Crombag
University of Leyden
Education Research Center
Boerhaavelaan 2
2334 EN Leyden, THE NETHERLANDS

Bryan Dallman
AFHRL/LRT
Lowry AFB, CO 80230

Dr. Joel Davis
Office of Naval Research
Code 1141NP
800 North Quincy Street
Arlington, VA 22217-5000

Dr. Sharon Derry
Florida State University
Department of Psychology
Tallahassee, FL 32306

Dr. R. K. Dismukes
Associate Director for Life Sci
AFOSR
Bolling AFB
Washington, DC 20332

Dr. Emanuel Donchin
University of Illinois
Department of Psychology
Champaign, IL 61820

Defense Technical (12 copies)
Information Center
Cameron Station, Bldg 5
Alexandria, VA 22314
Attn: TC

Streitkraefteamt, Abteilung I
Dezernat Wehrpsychologie
Postfach 20 50 03
D-5300 Bonn 2
FEDERAL REPUBLIC OF GERMANY

Dr. Ford Ebner
Brown University
Anatomy Department
Medical School
Providence, RI 02912

Dr. Jeffrey Elman
University of California,
San Diego
Department of Linguistics, C-008
La Jolla, CA 92093

Dr. Susan Embretson
University of Kansas
Psychology Department
Lawrence, KS 66045

Dr. Randy Engle
Department of Psychology
University of South Carolina
Columbia, SC 29208

Dr. William Epstein
University of Wisconsin
W. J. Brogden Psychology Bldg.
1202 W. Johnson Street
Madison, WI 53706

ERIC Facility-Acquisitions
4833 Rugby Avenue
Bethesda, MD 20014

Dr. K. Anders Ericsson
University of Colorado
Department of Psychology
Boulder, CO 80309

Dr. Martha Farah
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

Dr. Beatrice J. Farr
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Marshall J. Farr
2520 North Vernon Street
Arlington, VA 22207

Dr. Pat Federico
Code 511
NPRDC
San Diego, CA 92152

Dr. Jerome A. Feldman
University of Rochester
Computer Science Department
Rochester, NY 14627

J. D. Fletcher
9931 Corsica Street
Vienna VA 22180

Dr. John R. Frederiksen
Bolt Beranek & Newman
50 Moulton Street
Cambridge, MA 02138

Dr. Michaela Gallagher
University of North Carolina
Department of Psychology
Chapel Hill, NC 27514

Dr. Don Gentner
Center for Human
Information Processing
University of California
La Jolla, CA 92093

Dr. Gene L. Gloye
Office of Naval Research
Detachment
1030 E. Green Street
Pasadena, CA 91106-2485

Dr. Sam Glucksberg
Princeton University
Department of Psychology
Green Hall
Princeton, NJ 08540

Dr. Daniel Gopher
Industrial Engineering
& Management
TECHNION
Haifa 32000 ISRAEL

Dr. Sherrie Gott
AFHRL/MODJ
Brooks AFB, TX 78235

Jordan Grafman, Ph.D.
Dept. of Clinical Investigation
Walter Reed Army Medical Center
6825 Georgia Ave., N. W.
Washington, DC 20307-5001

Dr. Wayne Gray
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

Dr. Bert Green
Johns Hopkins University
Department of Psychology
Charles & 34th Street
Baltimore, MD 21218

Dr. William Greenough
University of Illinois
Department of Psychology
Champaign, IL 61820

Dr. Stephen Grossberg
Center for Adaptive Syste
111 Cummington Street, Rm
Boston University
Boston, MA 02215

Dr. Muhammad K. Habib
University of North Caroli
Department of Biostatistic
Chapel Hill, NC 27514

Prof. Edward Haertel
School of Education
Stanford University
Stanford, CA 94305

Dr. Henry M. Halff
Halff Resources, Inc.
4918 33rd Road, North
Arlington, VA 22207

Dr. Cheryl Hamel
NTSC
Orlando, FL 32813

Dr. Ray Hannapel
Scientific and Engineerin
Personnel and Education
National Science Foundat
Washington, DC 20550

Stevan Harnad
Editor, The Behavioral a
Brain Sciences
20 Nassau Street, Suite 2
Princeton, NJ 08540

Dr. Steven A. Hillyard
Department of Neuroscien
University of California,
San Diego
La Jolla, CA 92093

Dr. Geoffrey Hinton
Carnegie-Mellon Universit
Computer Science Departm
Pittsburgh, PA 15213

Dr. John Holland
University of Michigan
2313 East Engineering
Ann Arbor, MI 48109

Dr. Lloyd Humphreys
University of Illinois
Department of Psychology
603 East Daniel Street
Champaign, IL 61820

Dr. Earl Hunt
Department of Psychology
University of Washington
Seattle, WA 98105

..
Dr. Huynh Huynh
College of Education
Univ. of South Carolina
Columbia, SC 29208

..
Dr. Alice Isen
Department of Psychology
University of Maryland
Catonsville, MD 21228

..
Pharm.-Chim. en Chef Jean Jacq
Div.de Psych.Centre de Recherches du
Service de Sante des Armees
108 Boulevard Pinel
69272 Lyon Cedex 03, FRANCE

..
Dr. Robert Jannarone
Department of Psychology
University of South Carolina
Columbia, SC 29208

..
COL Dennis W. Jarvi
Commander
AFHRL
Brooks AFB, TX 78235-5601

..
Chair, Depart. of Psychology
The Johns Hopkins University
Baltimore, MD 21218

..
Col. Dominique Jouslin de Noray
Etat-Major de l'Armee de Terre
Centre de Relations Humaines
3 Avenue Octave Greard
75007 Paris FRANCE

..
Dr. Marcel Just
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

..
Dr. Daniel Kahneman
The University of British Columbia
Department of Psychology
#154-2053 Main Mall
Vancouver, B.C. CANADA V6T 1Y7

..
Dr. Demetrios Karis
Grumman Aerospace Corporation
MS C04-14
Bethpage, NY 11714

..
Dr. Milton S. Katz
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

..
Dr. Steven W. Keele
Department of Psychology
University of Oregon
Eugene, OR 97403

..
Dr. Scott Kelso
Haskins Laboratories,
270 Crown Street
New Haven, CT 06510

..
Dr. David Kieras
University of Michigan
Tech.Comm.College of Engineering
1223 E. Engineering Building
Ann Arbor, MI 48109

..
Dr. David Klahr
Carnegie-Mellon University
Department of Psychology
Schenley Park
Pittsburgh, PA 15213

..
Dr. Sylvan Kornblum
University of Michigan
Mental Health Research Institute
205 Washtenaw Place
Ann Arbor, MI 48109

..
Dr. Stephen Kosslyn
Harvard University
1236 William James Hall
33 Kirkland St.
Cambridge, MA 02138

..
Dr. David H. Krantz
2 Washington Square Village
Apt. # 15J
New York, NY 10012

..
Dr. Marcy Lansman
University of North Carolina
The L. L. Thurstone Lab.
Davie Hall 013A
Chapel Hill, NC 27514

..
Dr. Michael Levine
Educational Psychology
210 Education Bldg.
University of Illinois
Champaign, IL 61801

..
Dr. Bob Lloyd
Dept. of Geography
University of South Carolina
Columbia, SC 29208

..
Dr. Gary Lynch
University of California
Center for the Neurobiology of
Learning and Memory
Irvine, CA 92717

..
Dr. Don Lyon
P. O. Box 44
Higley, AZ 85236

..
Dr. James McBride
Psychological Corporation
Harcourt,Brace, Javanovich Inc.
1250 West 6th Street
San Diego, CA 92101

..
Dr. Jay McClelland
Department of Psychology
Carnegie-Mellon University
Pittsburgh, PA 15213

..
Dr. James L. McGaugh
Center for the Neurobiology
of Learning and Memory
University of California, Irvine
Irvine, CA 92717

..
Dr. Joe McLachlan
Navy Personnel R&D Center
San Diego, CA 92152

..
Dr. James McMichael
Assistant for MPT Research,
Development, and Studies
NAVOP 01B7
Washington, DC 20370

..
Dr. George A. Miller
Department of Psychology
Green Hall
Princeton University
Princeton, NJ 08540

..
Dr. Tom Moran
Xerox PARC
3333 Coyote Hill Road
Palo Alto, CA 94304

..
Dr. David Navon
Institute for Cognitive Science
University of California
La Jolla, CA 92093

..
Assistant for MPT Research,
Development and Studies
NAVOP 01B7
Washington, DC 20370

..
Leadership Management Education
and Training Project Officer,
Naval Medical Command
Code 05C
Washington, DC 20372

..
Dr. Allen Newell
Department of Psychology
Carnegie-Mellon University
Schenley Park
Pittsburgh, PA 15213

..
Dr. Mary Jo Nissen
University of Minnesota
N218 Elliott Hall
Minneapolis, MN 55455

..
Dr. Donald A. Norman
Institute for Cognitive Science
University of California
La Jolla, CA 92093

..
Director, Training Laboratory,
NPRDC (Code 05)
San Diego, CA 92152

..
Director, Manpower and Personnel
Laboratory, NPRDC (Code 06)
San Diego, CA 92152

..
Director, Human Factors
& Organizational Systems Lab,
NPRDC (Code 07)
San Diego, CA 92152

..
Fleet Support Office,
NPRDC (Code 301)
San Diego, CA 92152

..
Library, NPRDC
Code P201L
San Diego, CA 92152

..
Dr. Harry F. O'Neil, Jr.
University of Southern California
School of Education -- WPH 801
Dept. of Educational
Psychology and Technology
Los Angeles, CA 90089-0031

..
Office of Naval Research,
Code 1141NP
800 N. Quincy Street
Arlington, VA 22217-5000

..
Office of Naval Research,
Code 1142
800 N. Quincy St.
Arlington, VA 22217-5000

..
Office of Naval Research,
Code 1142EP
800 N. Quincy Street
Arlington, VA 22217-5000

..
Office of Naval Research (6 Copies)
Code 1142PT
800 N. Quincy Street
Arlington, VA 22217-5000

..
Psychologist
Office of Naval Research
Branch Office, London
Box 39
FPO New York, NY 09510

..
Special Assistant for Marine
Corps Matters, ONR Code 00MC
800 N. Quincy St.
Arlington, VA 22217-5000

..
Psychologist
Office of Naval Research
Liaison Office, Far East
APO San Francisco, CA 96503

..
Dr. Judith Orasanu
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

..
Daira Paulson
Code 52 - Training Systems
Navy Personnel R&D Center
San Diego, CA 92152

..
Dr. James Paulson
Department of Psychology
Portland State University
P.O. Box 751
Portland, OR 97207

..
Dr. Douglas Pearse
DCIEM
Box 2000
Downsview, Ontario
CANADA

..
Dr. James W. Pellegrino
University of California,
Santa Barbara
Department of Psychology
Santa Barbara, CA 93106

..
Military Assistant for Training and
Personnel Technology,
OUSD (R & E)
Room 3D129, The Pentagon
Washington, DC 20301

..
Dr. Ray Perez
ARI (PERI-II)
5001 Eisenhower Avenue
Alexandria, VA 2233

..
Dr. Steven Pinker
Department of Psychology
E10-018
M.I.T.
Cambridge, MA

..
Dr. Mike Posner
University of Oregon
Department of Psychology
Eugene, OR 97403

..
Dr. Karl Pribram
Stanford University
Department of Psychology
Bldg. 4201 -- Jordan Hall
Stanford, CA 94305

..
Lt. Jose Puente Ontanilla
C/Santisima Trinidad, 8, 4 E
28010 Madrid
SPAIN

..
Dr. Daniel Reisberg
Department of Psychology
New School for Social Research
65 Fifth Avenue
New York, NY 10003

..
Dr. David Rumelhart
Center for Human
Information Processing
Univ. of California
La Jolla, CA 92093

..
Ms. Riitta Ruotsalainen
Gen.Hqtr. Training Section
Military Psychology Office
PL 919
SF-00101 Helsinki 10, FINLAND

..
Dr. E. L. Saltzman
Haskins Laboratories
270 Crown Street
New Haven, CT 06510

..
Dr. Arthur Samuel
Yale University
Department of Psychology
Box 11A, Yale Station
New Haven, CT 06520

..
Dr. Robert Sasmor
Army Research Institute
5001 Eisenhower Avenue
Alexandria, VA 22333

..
Mrs. Birgitte Schneidelbach
Forsvarets Center for Ledera
Christianshavns Voldgade 8
1424 Kobenhavn K
DENMARK

..
Dr. Walter Schneider
Learning R&D Center
University of Pittsburgh
3939 O'Hara Street
Pittsburgh, PA 15260

..
Dr. Hans-Willi Schroiff
Inst.fuer Psych.der RWTH Aac
Jaegerstrasse zwischen 17 u.
5100 Aachen
WEST GERMANY

..
Dr. Robert J. Seidel
US Army Research Institute
5001 Eisenhower Ave.
Alexandria, VA 22333

..
Dr. T. B. Sheridan
Dept.of Mech.Eng. MIT
Cambridge, MA 02139

..
LtC Juhani Sinivuo
Gen.Hqtrs. Training Section
Military Psychology Office
PL 919
SF-00101 Helsinki 10, FINLAND

..
Dr. Edward E. Smith
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

..
Dr. Richard E. Snow
Department of Psychology
Stanford University
Stanford, CA 94306

..
Dr. Kathryn T. Spoehr
Brown University
Department of Psychology
Providence, RI 02912

..
James J. Staszewski
Research Associate
Carnegie-Mellon University
Dept. Psych. Schenley Park
Pittsburgh, PA 15213

..
Dr. Ted Steinke
Dept. of Geography
University of South Carolina
Columbia, SC 29208

..
Dr. Robert Sternberg
Department of Psychology
Yale University
Box 11A, Yale Station
New Haven, CT 06520

..
Dr. Saul Sternberg
University of Pennsylvania
Department of Psychology
3815 Walnut Street
Philadelphia, PA 19104

..
Dr. Paul J. Sticha
Senior Staff Scientist
Training Research Division
HumRRO
1100 S. Washington
Alexandria, VA 22314

..
Medecin Philippe Stivalet
Div. Psych.Centre Recherches du
Service de Sante des Armees
108 Boulevard Pinel
69272 Lyon Cedex 03, FRANCE

..
Mr. Brad Sympson
Navy Personnel R&D Center
San Diego, CA 92152

..
Dr. John Tangney
AFOSR/NL
Bolling AFB, DC 20332

..
Dr. Kikumi Tatsuoka
CERL 252 Eng.Research
Laboratory
Urbana, IL 61801

..
Dr. Richard F. Thompson
Stanford University
Department of Psychology
Bldg. 4201 -- Jordan Hall
Stanford, CA 94305

..
Dr. Michael T. Turvey
Haskins Laboratories
270 Crown Street
New Haven, CT 06510

..
Dr. Amos Tversky
Stanford University
Dept. of Psychology
Stanford, CA 94305

..
Dr. James Tweeddale
Technical Director
Navy Personnel R&D Center
San Diego, CA 92152

..
Dr. V. R. R. Uppuluri
Union Carbide Corporation
Nuclear Division
P. O. Box Y
Oak Ridge, TN 37830

..
Hqrts.U. S. Marine Corps
Code MPI-20
Washington, DC 20380

..
Dr. William Uttal
NOSC, Hawaii Lab
Box 997
Kailua, HI 96734

..
Dr. J. W. M. Van Breukelen
Afd.Soc.Wetenschappelijk Onderzoek/DPKM
Admiraliteitsgebouw
Van Der Burchlaan 31 Kr. 376
2500 ES 's-Gravenhage, NETHERLANDS

..
Dr. Howard Wainer
Division of Psychological Studies
Educational Testing Service
Princeton, NJ 08541

..
Dr. Beth Warren
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02138

..
Dr. H. J. M. Wassenberg
Head Dept.of Beh.Sci.Roy.Neths.A.F.
Afd. Gedragswetenschappen/DPKLv
Binckhorstlaan 135 Kr. 2L4
2516 BA 's-Gravenhage, NETHERLANDS

..
Dr. Norman M. Weinberger
University of California
Center for the Neurobiology
of Learning and Memory
Irvine, CA 92717

..
Dr. Shih-Sung Wen
Jackson State University
1325 J. R. Lynch Street
Jackson, MS 39217

..
Dr. Douglas Wetzel
Code 12
Navy Personnel R&D Center
San Diego, CA 92152

..
Dr. Barbara White
Bolt Beranek & Newman, Inc.
10 Moulton Street
Cambridge, MA 02238

..
Dr. Barry Whitsel
University of North Carolina
Department of Physiology
Medical School
Chapel Hill, NC 27514

..
Dr. Christopher Wickens
Department of Psychology
University of Illinois
Champaign, IL 61820

..
Dr. Robert A. Wisher
U.S. Army Institute for the
Behavioral and Social Sciences
5001 Eisenhower Avenue
Alexandria, VA 22333

..
Dr. Martin F. Wiskoff
Navy Personnel R & D Center
San Diego, CA 92152

..
Mr. John H. Wolfe
Navy Personnel R&D Center
San Diego, CA 92152

..
Dr. Donald Woodward
Office of Naval Research
Code 1141NP
800 North Quincy Street
Arlington, VA 22217-5000

..
Dr. Wallace Wulfeck, III
Navy Personnel R&D Center
San Diego, CA 92152

..
Dr. Joe Yasatuke
AFHRL/LRT
Lowry AFB, CO 80230

..
Dr. Joseph L. Young
Memory & Cognitive
Processes
National Science Foundation
Washington, DC 20550

..
Dr. Steven Zornetzer
Office of Naval Research
Code 1140
800 N. Quincy St.
Arlington, VA 22217-5000

..

END
7-87
DTIC

END
7-87
DTIC