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by

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Abstract

A DEVELOPMENTAL STUDY OF SPEED AND STRATEGY IN VISUAL INFORMATION PROCESSING, USING BACKWARD MASKING

by

Joanna Blake

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The purpose of this study was to explore the possibility that age differences in short-term memory capacity might be due to age differences in speed or strategy for processing input. Processing speed and strategy were investigated by means of a backward masking technique, in which a target stimulus array, presented in one field of a tachistoscope, was followed at variable intervals by a masking array, presented in another field. The stimulus arrays contained one, two, or four forms, placed $.5^{\circ}$ above, below, and, in the case of the four-form arrays, to the left and right of a central fixation point. The masking array contained forms in the same positions as the four-form arrays and was made up of some of the forms contained in the stimulus set. It was assumed that this type of mask, similar to the target and spatially overlapping it, had the effect of pre-empting the mechanism used to analyze the target, thereby stopping processing of the target. The evidence supporting this assumption was discussed. Given this assumption, the interval between the onset of the target array and the onset of the masking array was considered as processing time.

Comparisons of processing time were made between six children

four years of age, six children eight years of age, and six college students. The target array was shown to the youngest children for 30 msec. duration and to the eight-year-olds and adults for 15 msec. duration. For all _S_s, the target array was preceded by a fixation field, presented for 750 msec., and a dark interval of 100 msec. duration. It was followed by a variable dark interval and the masking array, presented for 100 msec. The luminance levels for the fixation, target, and masking fields were approximately 2.6, 3.0, and 3.5 ml., respectively. The interval between the target and masking arrays was 0, 15, 30, 60, 90, 150, or 250 msec. In addition, trials without the mask were given for multiple-stimulus arrays. Each _S_ received a block of six trials at each ISI under each stimulus array condition. There were four stimulus conditions: one form, two-form, and four-form arrays,in which _S_s were to report all forms, and four-form arrays in which they were to report only two of the forms. All _S_s received the same random order of stimulus array conditions but different random orders of ISIs. On each trial, _S_s pointed on a response card to the forms that they had seen.

Mean accuracy at each ISI, corrected for chance, was compared across stimulus array conditions and age groups. The main features of the results were as follows:

1) _S_s of all age groups processed one form at the same rate under all stimulus array conditions, except the selectivity condition. Under this condition, four-year-olds processed one form at high accuracy only on trials without the mask.

2) Four-year-olds were slower than older _S_s in rate of processing the

second form and did not process more than two forms. Eight-year-olds were slower than adults in processing the third form and reached an asymptote of 2.3 forms. Adults reached an asymptote of 2.6 forms.

3) Eight-year-olds and adults showed a parallel independent processing strategy as array size was increased from one to two forms, in that they processed twice as much from two-form arrays as from one-form arrays at all ISIs. Four-year-olds processed more from two than from one-form arrays at most ISIs, but not twice as much. Adults processed slightly more from four-form arrays, as compared to two-form arrays, while eight-year-olds processed about the same from both, and four-year-olds processed less from four than from two-form arrays.

4) For all groups, processing of two forms was slower under the selectivity condition than under whole report for two-form and four-form arrays, although the differences between array conditions were not significant for eight-year-olds.

5) Children's accuracy on their first response was higher than that of adults at 0 msec. ISI, indicating possible age differences in masking effects at the shortest delay.

6) The relative difficulty of the twelve forms used was very similar across age groups, but age differences in form preference were apparent.

Possible bases for the discrepancy between the strategy used by older *Ss* in this study and other studies were reviewed. The implications of the findings for models of information processing and theories of perceptual and cognitive development were discussed. Age differences in masking effects at the shortest delay were related to possible age differences in perception of successiveness.

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CHAPTER I

INTRODUCTION

An information processing approach to visual perception is an approach which considers sensation, perception, memory, and thought to be on a continuum of cognitive activity (Haber, 1969b) They are viewed as mutually interdependent and interacting processes rather than as separate static structural systems. As such, it is difficult to know where one process ends and another begins. For example, with regard to perception and memory, this approach assumes that "perceptual processes cannot be studied or analyzed independent of memorial ones, since recoding and preservation of information occurs at all stages of information processing" (Haber, 1969b, p.2).

The emphasis of this approach is then on the analysis of process rather than of structure and of not one process but a series of processes which interact. There are, however, stages in this sequence of processes. A response to a stimulus does not occur immediately but must go through a number of operations which take time. Information does not simply flow through a passive organism, but rather it is manipulated at several points by a very active organism. An information processing analysis attempts to chart these operations by measuring responses at varying points in time after stimulus onset. The aim is to divide the "total time from stimulus onset to the occurrence of the perceptual response ... into intervals, each characterized by a different operation" (Haber, 1969b, p.4). This aim is theoretically expressed in flow charts which attempt to label operations and the order in which they occur. Such models have been constructed by

Broadbent (1958), Norman (1968), Shiffrin and Atkinson (1969), and Sperling (1963, 1967), among others.

This approach, which conceptualizes input as information moving through the system in stages, has been used in recent studies which attempt to specify exactly what develops with age with respect to visual perception and short-term memory (e.g. Haith, 1970).

Developmental Studies of Visual Information Processing

Several studies have pointed to a lower limit in the amount of information, defined in terms of the complexity of random shapes, that both preschool children (Munsinger, 1965; Santa Barbara and Paré, 1965) and elementary school children (Munsinger and Kessen, 1966) can handle, as compared to adults. One reason for the lower limit is that children are less able than adults to make use of the symmetry or redundancy of a pattern to reduce information overload as complexity increases (Munsinger and Kessen, 1966; Munsinger, 1967).

A recent study by Haith, Morrison, Sheingold and Mindes (1970) demonstrated a capacity limit in preschool children with respect to the number of items they could process or remember from stimulus arrays containing varying numbers of forms. Five-year-olds could report a maximum of only two items whether they were shown two, three, or four items. If anything, the number of items that they reported correctly declined slightly as the number presented increased, whereas adults reported an increasingly larger number from increasingly larger arrays. Interestingly, this limit was not found for spatial information (Finkel, 1971). When five-year-olds were shown matrices which contained varying numbers of black discs up to five, they could place approximately four discs in their correct positions. However, as soon as a single disc was replaced by a form, their memory capacity dropped again to two items. This study does not demonstrate that five-year-olds' memory for spatial position is almost equal to that of adults, since adult capacity may be much higher than five positions, but simply that their own memory for position is relatively higher than for item information.

Subsequent studies conducted by Haith and his associates have been directed towards determining whether the capacity limit for item information found in five-year-olds is attributable to 1) age differences in the sensitivity of the visual system, both foveal (Haith, Morrison, and Sheingold, 1970) and nonfoveal (Morrison, Lott, and Dulay, cited in Haith, 1970; 2) speed of visual processing of single and multiple stimuli (Liss and Haith, 1970); or 3) differences in short-term visual storage capacity or in rate of decay of the visual trace (Sheingold, 1970). Age differences in scanning strategies, for which there is good evidence (e.g. Vurpillot, 1968), could be eliminated as a possible source of the age difference in short-term memory capacity since the items were presented tachistoscopically at an exposure duration too short tc permit eye movements (150 msec.)

Visual sensitivity is apparently fairly well developed at five years. Recognition accuracy for single forms presented for 20 msec. duration at a luminance level of 1.9 foot-lamberts is about the same for five-year-olds as for adults. At this duration and luminance level, both groups achieve 80% to 90% accuracy or, in other words, are at point where they are just beginning to make errors. At 10 msec. duration and the same luminance level, however, the performance of five-year-olds drops to 10% accuracy, while that of adults drops only slightly (Haith, Morrison, and Sheingold, 1970). Since the stimuli in the original experiment were presented for 150 msec., more than four times the 80% threshold for one item, the role of foveal sensitivity in the age differences found is not considered to be significant.

However, the stimuli in the original experiment were not presented in the center of the fovea as they were in the threshold study. Rather, they were presented in a circular array with each item about 1.5° from the central fixation point. Since adult acuity has been found to decrease rapidly even with 1° of visual angle from the center of the fovea (Eriksen and Spencer, 1969), it was necessary to determine if the decrease is the same for five-year-olds. With a 20 msec. stimulus duration, however, it seems that five-year-olds do not make errors in recognition until the form is at least 4° from the center of the fovea (Morrison, Lott, and Dulay, cited in Haith, 1970). Thus, the age differences in short-term memory capacity cannot be attributed to a difference in nonfoveal sensitivity.

The similar performance of adults and children at a a 20 msec. exposure duration does not necessarily mean that adults and children were taking the same amount of time to process the stimulus. Sperling (1960) has demonstrated that the visual image of the stimulus persists beyond the stimulus exposure for about one quarter of a second, and this finding has been confirmed by many investigators (e.g. Averbach and Coriell, cited in Averbach and Sperling, 1961; Haber, 1969a; Smith and Carey, 1966). Thus, measurement of time available for processing a stimulus requires control over persistence of the image. Sperling attempted to do this by presentation of a masking stimulus after the original stimulus, following a procedure devised by Baxt. The masking stimulus is assumed to interrupt or stop processing of the first stimulus. Thus, the time available for processing the first stimulus is the period from its onset to onset of the mask, and this interval can be varied. Liss and Haith (1970) used a masking procedure to measure processing time in five-year-olds and adults. The mask was presented at decreasing intervals before or after the target stimulus until _S_'s recognition accuracy was just above chance level. There were two tasks: an identification of line orientation task, in which _S_s had to say whether a line was horizontal or vertical, and a visual search task, in which _S_s had to locate the position of a given line whose orientation differed from the other eight lines in the stimulus. In both tasks, the interstimulus interval between the stimulus and the masking array at which chance accuracy or threshold was reached was longer for five-year-olds than for adults. However, in the identification task, the age difference was not greater under backward as compared to forward masking. Thus, it was attributed to age differences in motivation, task comprehension,or use of partial cues, rather than to age differences in processing time. Only in the visual search task was the age difference greater under backward than under forward masking. Thus, this difference was considered to include age differences in processing time as well as possible age differences unrelated to processing time. Liss and Haith surmise that preschoolers might show slower processing times in the visual search task either because they are using a serial strategy, while adults are using a parallel strategy, or because they are applying the same strategy at a slower rate. This question will be discussed more fully below.

Finally, Sheingold (1970) adapted Averbach and Coriell's partial report procedure for use with five-year-olds to determine if their visual image persists as long as it does for adults. The partial report procedure consists of presenting an array of items followed by an indicator (e.g., a tone or arrow) given at varying intervals after exposure of the array. The indicator limits the number of items which S has to report or, in Sperling's (1960) terms, samples the information which S still has available in the visual trace. The indicator can ask for one item (Averbach and Coriell, in Averbach and Sperling, 1961) or a row of items (Sperling, 1960) or a category of items (Sperling, 1960; Dick, 1969). For example, a high tone can be used to indicate that the top row should be reported, a medium tone to indicate report of the middle row, and a low tone report of the bottom row. The partial reports at a given delay interval can be averaged, this average multiplied by the number of rows, and the product is an estimate of what S can still see at that interval. The purpose of this procedure is to avoid the problem of Ss seeing more than they can report before the trace fades.

As stated earlier, Sperling and many other investigators have determined that for adults, under normal conditions with white pre- and post-fields, the image persists for about a quarter of a second. Haber and Standing (1970) directly measured the duration of the image by having Ss adjust clicks until they exactly coincided with the onset and offset of the stimulus. This direct method also showed a persistence duration of about a quarter of a second.

Sheingold presented an array of eight items followed by a teardrop indicator pointing to one of the eight positions. Ss were to report the item which had been shown in that position. Sheingold found that the performance of five-year-old children and adults declined at about the same rate as the indicator was delayed by 50 to 150 msec. At 50 msec. delay, adults reported a total of six items correctly and five-year-olds slightly more than six. At 100 msec. delay, adults reported a total of five items and children about four items. Between 100 and 150 msec. delay, adults dropped only about one-half item and children only about one-quarter item. At 200 msec. delay, both groups improved about a half an item, and adults continued to improve at 250 msec., up to a total of almost six items again. At 250 msec., however, children's performance abruptly dropped to two items, their short-term memory limit. After 250 msec. indicator delay, adult performance gradually declined to four items, presumably their short-term memory limit. Thus, the visual trace of five-year-olds seemed to fade about 50 msec. earlier than that of adults. Haith attributes the rise in adult performance after 150 msec. to a switch in their strategy. As the delay increased, he thinks that adults may have attempted to encode items by labeling and rehearsing them.

With no delay of the indicator, there is an interesting finding. Children did worse than adults and worse than they, themselves, did with a 50 msec. delay. They reported an average of slightly less than six items at 0 msec. delay, as compared to somewhat more than six items at 50 msec. delay, whereas adults reported an average of slightly more than seven items at 0 msec. delay and about six items at 50 msec. delay. Haith (1970) interprets the improvement in children's performance between 0 and 50 msec. delay as meaning that children had difficulty with simultaneously presented information and that they needed some time to process the array before they could attend to the indicator.

Finkel (1971) found that elementary school children and adults showed no decline at all in the availability of spatial information as the indicator was delayed from 0 to 1000 msec. In this study, _S_s were shown four forms distributed around the center of a 3 x 3 matrix. A test matrix was then presented at intervals of up to 1000 msec. after the original array. The test matrix contained one of the original forms in the center and black discs in the positions which had been filled in the original array. _S_'s task was to point to the black disc which was in the same position that the test form had occupied in the original array. Unfortunately, five-year-olds were not able to perform much above chance in this partial report task. Adults located a total of about six and one-half items correctly out of eight items at 0 and 1000 msec. delay and somewhat more at the intervening ISIs.

Sixth-grade children improved from a total of five positions correct at 0 msec. delay to a peak of almost seven at 500 msec. delay and then dropped to a total of six positions at 1000 msec. delay. Third-grade children reported a total of five positions at all delays except 50 and 150 msec. where their totals were slightly higher. Thus, it seems that relative to form information, position information is encoded very rapidly into a more stable form with little loss of information or decay. The results of this study do not agree with the results of other studies (e.g. Dick, 1969; Turvey and Kravetz, 1970) which have found in partial report tasks that spatial information does decay over delay intervals of up to 1000 msec. However, these studies differed from Finkel's study in that Ss were required to report the items (letters) of a particular row (top, middle, or bottom). Thus, the task involved both spatial and item information: Ss had to remember not only what row each item was in but all three items of a particular row. In Finkel's task, Ss were given an item and had to remember only its location.

Haith (1970) concludes from this series of studies that there is little difference between five-year-old children and adults in their processing of a single visual stimulus. However, the five-year-old is at a disadvantage when he is presented with multiple-stimulus arrays, as in the short-term memory task, the visual search task, and the partial report task with a simultaneous indicator. Haith attributes this disadvantage to a lack of strategy for processing each item one at a time or serially. However, in the visual search task, it seems that the children may have lacked a strategy for processing the items in parallel.

Finkel's (1971) study also points to possible age differences in ability to process information in parallel. As soon as four-year-olds had to remember one of the items in a matrix, their memory for the positions filled abruptly dropped from approximately four positions to about two. Adults, on the other hand, showed a negligible decrease in position memory when they also had to remember one item, but their performance continued to decline gradually as they were required to remember more items. Thus, adults seemed to be able to process spatial and item information in parallel, and their performance declined only as their limit for processing items was reached. Children, however, seemed unable to process these two types of information in parallel. As soon as one item was added to the four positions which they had to remember, they could no longer remember four positions, even though adding another position had little effect.

The present research followed this series of studies in an attempt to determine if the two-item short-term memory limit of preschoolers, found by Haith et al. (1970), can, in fact, be attributed to an age difference in processing strategy or if it is due simply to an age difference in processing speed. Before further discussion of the research, possible strategies which might be used in processing information will be examined, as well as the methods which have been employed to discriminate between them.

Serial and Parallel Processing

The distinction between serial and parallel processing arises from models for pattern recognition by computers. According to Selfridge and Neisser (1960), there are two fundamentally different procedures which can be followed in devising a program for feature recognition. "In sequential processing the features are inspected in a predetermined order, the outcome of each test determining the next step"(p. 65). The sequential program asks a question about the input letter, and the answer to that question determines the next question, and so forth. In parallel processing, on the other hand, "all the questions would be asked at once, and all the answers presented simultaneously to the decision-maker" (p. 66). One can think of many little demons shouting answers all at once to a decision-making demon, hence the name Pandemonium for Selfridge's model of parallel processing. A parallel model is considered to be both more efficient, in that a change or correction is incorporated more easily, and more flexible, in that decisions need not be binary but can reflect the relative weights of various features in a series of letters or patterns. Selfridge and Neisser also state here that "parallel processing seems to be the human way of handling pattern recognition" (p. 66), at least in speech perception or depth perception, for example. The Pandemonium model has six levels: input, clean-up, inspection of features,comparison with learned-feature distribution, computation with learned-feature distribution, computation of probabilities, and decision. Thus, although the features are processed in parallel, the structure of the program is hierarchical.

Neisser (1967) has further elaborated the Pandemonium model and evaluated its relevance to human cognitive systems. According to Neisser, the model implies two forms of parallel processing: spatially parallel processing and operationally parallel processing. Spatially parallel processing means that the same operation is carried out simultaneously across the whole input. Operationally parallel processing means that operations are carried out independently and simultaneously. Independence of operations means that one operation has no effect upon another, either with respect to its outcome or with respect to the time it takes. Simultaneity of operations means, of course, that operations begin and end at the same time.

According to Neisser, the application of spatially parallel processing to human information processing is not plausible. He maintains that we really cannot deal with the whole visual input at once. Human processing is characterized rather by spatially serial processing. Only part of the input, the field of focal attention, is analyzed at one time. However, this stage of attentive analysis is preceded by a stage which <u>can</u> be characterized by spatially parallel processing, although this stage is restricted to preattentive processing. Preattentive processes serve to segregate the field into units upon which attentive processes can then focus. They guide movement and redirect attention, but they do not perform any feature analysis. They can deal with "only crude properties of the stimuli -- movement, general location, brightness" (Neisser, 1967, p. 301). Thus, feature analysis is limited to the attentive level, which analyzes items in a serial fashion. If items are "to be identified, they must be synthesized one at a time" (p. 103). Neisser's model is thus a sequential model, since the attentive stage of processing succeeds and depends upon the preattentive stage of processing. However, it appears that processing of features can involve parallel operations. For Neisser, parallel operations are characterized only by independence and not necessarily by simultaneity.

For other investigators, however, parallel operations must occur simultaneously, but they can be independent or dependent. Dependence of operations means that the more items there are to operated upon, the slower are the operations performed on each item. In other words, the operations performed on an array of items occur simultaneously, but they share a total processing time which is limited. Thus, if the number of items in the array is increased, there is less time to be spent on each item. More time is then needed in order to process each item completely.

Parallel dependent processing is then similar to serial processing in that both imply a limited capacity operator (Liss and Reeves, 1971). In serial processing, the limited capacity operator cannot attend to all the features simultaneously. In parallel dependent processing, there is mutual interference among the features being processed simultaneously. In parallel independent processing, on the other hand, "the processing of each feature does not interfere at all with the simultaneous processing of other features, [and thus,] no limited capacity system is in evidence " (Liss and Reeves, 1971, p. 3).

Neisser, Sternberg, and other investigators have used reaction time experiments to discriminate between serial and parallel operations in processing. These studies and the types of processing which they have demonstrated will now be examined briefly.

Serial Versus Parallel Processing in Reaction Time Studies

Neisser has developed a visual search task to investigate processing strategies. In his task, the subject looks for one or more targets in arrays varying in size and pushes a button when he finds the targets. If search latencies increase as number of targets or array size increases, then processing is considered to be serial. If the subject can find several targets as fast as one, this is interpreted as parallel independent processing. Neisser, Novick, and Lazar (1963) found that practiced *Ss* could search for as many as ten items as fast as one. However, even with practice, Neisser (1963) found that *Ss* still took longer to look through arrays containing six items per row than arrays with only two items per row, though not quite three times as long.

In Sternberg's task (e.g., Sternberg, 1966), the subject is given a set of stimuli varying in number which he has to memorize. He is then presented with a test stimulus and has to decide whether or not it is one of the memorized set. Thus, in this procedure, the subject searches through a memorized set which varies in size, in contrast to Neisser's procedure in which the subject searches through a display set varying in size. Sternberg (1966) found serial processing in his task. Latencies for responding yes and no increased monotonically with the number of symbols in the memorized set. Furthermore, there was no difference between yes and no latencies, indicating that the search was exhaustive rather than self-terminating. These findings imply that Ss compared the test stimulus to each symbol in memory one at a time, in a serial manner, with each comparison requiring about the same amount of time. The slope of the latency function showed that this time was about 35 msec. per symbol. Practice had no effect on the shape of the linear function nor on the rate of scanning.

Neisser (1967) suggests that the discrepancy between Sternberg's results and his own may be attributable to the nature of the tasks. He calls Sternberg's procedure a character-classification task, in which S is encouraged to synthesize or construct each pattern first before making a comparison. In visual search, on the other hand, each letter may not be synthesized totally, but processing may be restricted to only certain features. It seems plausible that Ss can restrict their processing to only certain features if the set searched is visually present, whereas they are unable to restrict their processing in searching a memorized set.

Further support for this interpretation is provided by the results of a same-different study conducted by Donderi and Zelnicker (1969). Ss were shown tachistoscopically an array of shapes varying in number from two to thirteen. Ss has to decide if all the shapes were the same or one differed. They did not know beforehand what shapes they would see on each trial. Decision latencies in this study showed no increase as the number of shapes was increased, thus indicating parallel independent processing in this task. It may be that in this task, only one form is synthesized totally and then compared to others with respect to certain features only, as in visual search. Thus, increasing the number of comparisons would not increase RT.

Developmental Studies of Serial Versus Parallel Processing, Using RT

Comparison of elementary school children and adults on visual search tasks indicates that children of this age have longer search latencies than adults, but there are discrepant findings with respect to qualitative differences. Forsman (1967) found that the search latencies of third-grade children increased more than those of adults as the complexity of the random shapes used for the target and array was increased. _S_s' reports following the task implied that this age difference might be due to the fact that adults sampled only parts of the more complex targets, while third-graders tended to use the whole shape as the object of search.

Gibson and Yonas (1966) found, however, that elementary school children as young as seven years could search for two target letters as fast as one. Furthermore, although their search times were increased when they had to search through a context of highly confusable letters, they were not increased more than those of adults.

Yonas and Gibson (1967) also found no qualitative differences between elementary school children and adults in a Sternberg-type task. The positive, memorized, set was either one letter (E), three letters with dissimilar features (AOF) or three letters sharing the feature of diagonality (ANV). Children's latencies for deciding whether or not a single letter belonged to the memorized set were longer than adults but were not differentially affected by the type of positive set. All Ss were slower in searching a set of three items than a set of one item. With practice, latencies for all age groups decreased more with the ANV set than with the AOF set, thus suggesting that Ss began to look only for the single differentiating feature. However, latencies under the ANV set still did not approach latencies under the single item, E, set.

Yonas (1969) repeated the task with additional practice trials and different types of training experiences. With a great deal of practice, Ss could search the ANV set as fast as the E set. Training on discrimination of the diagonality feature also resulted in decreased latencies, as compared to training on a different, irrelevant feature and no training. The Ss were seven, eleven, and eighteen years of age, and all age groups showed similar effects of practice and training.

Bracey (1971) also found that that elementary school children did not differ qualitatively from adults in a Sternberg-type task. Ss of grades four, six, and eight showed a linear increase in response latency as the memorized set was increased from one to four items. Thus, like adults, it seems that they searched the items in memory one at a time, in serial fashion. However, the slope of the linear function indicated that the rate of scanning was about 50 msec. per item for all grade school children, somewhat slower than the 35 msec. per item rate which has been found for adults (Sternberg, 1966). When the test items were presented in noise, encoding time was increased for sixth and eighth-grade Ss, but scanning time was not.

In other words, with reaction time plotted against set size, degrading the input for older children resulted in a change in the intercept but not in the slope of the function. According to Sternberg (1967) the intercept represents the encoding stage, which involves filtering or refining operations, while the slope represents scanning time. The filtering or refining operations were apparently not performed as efficiently or completely by fourth graders, since degrading the input for these _S_s increased both the intercept, or rate of encoding, and the slope, or rate of scanning.

Morin, Hoving, and Konick (1971) found qualitative differences between kindergarten children and adults but not between fourth-grade children and adults in a modified same-different task. _S_s were shown two items and had to decide if they were from the same set. Older _S_s showed serial scanning of the set for the first item if it was composed of arbitrarily grouped items. However, if it was composed of items belonging to a familiar class, reaction times did not increase as set size was increased. The authors suggest that this is because the _S_s were encoding the two items by their class names and comparing these names. For kindergarten children, increasing set size for either familiar or arbitrary sets increased decision latencies. Thus, they appeared to be searching both types of sets in series. Moreover, increasing the set size for either the first or second item increased their latencies. Thus, unlike older _S_s, they did not always search the set of the first item, presumably because they did not rehearse. According to the authors, rehearsal may focus attention on the set of the first item and make search of this set more likely than search of the second-item set.

These developmental studies using search tasks point to quantitative differences between children and adults, in that children's rate of processing is slower. However, except for the Forsman (1967) study, qualitative differences appear to be limited to encoding operations. Little difference with respect to serial and parallel processing strategies is revealed in these studies. Children, like adults, were found to search for two targets as fast as one in a visual display and to compare a test item to a memorized set of items one at a time in serial fashion. Reaction time may not be the ideal measure to use in investigating age differences in processing speed or strategy, however. Even the age differences found in rate of processing are ambiguous, since they might be attributable to age differences in decision time or scanning time. This question will now be examined.

Reaction Time as a Measure of Serial and Parallel Processing

If, as Neisser suggests, processing in visual search does not require total synthesis of each target symbol or symbol in the array, then it is difficult to see how search time in this task can discriminate between serial and parallel operations in processing. It is very likely that processing in this task is restricted to very few features or even one feature that the targets share. For example, Yonas and Gibson (1966) note that the two targets in their task, G and R, had a curve in common which the other letters did not. Thus, *S*s may have been able to simply extract this feature and search for it. The fact that they could search for both targets as fast as one does not, therefore, indicate parallel processing, as the authors point out.

The fact that visual search tasks may be insensitive to discriminating between serial and parallel models of the encoding process itself has been underlined by Eriksen and Spencer (1969). They gave _S_s a detection task in which they were to search for the target letter A in sequences made up of the letters A,T, and U. The sequences contained from one to nine letters. Each letter was shown for 2 msec., and the inter-letter interval was varied between 5 and 30 msec. With their yes and no detection responses, _S_s gave a confidence rating, which was analyzed in terms of _d_s. There was no effect of input rate on _d_s. A subsequent experiment showed that _d_s was higher at 30 msec. ISI than at 90 msec. or 150 msec. ISI, possibly, the authors suggest, because it is difficult to maintain fixation at the longer ISIs.

The fact that there was no effect of input rate between 5 and 30 msec. ISI does not mean, according to the authors, that we have a multi-channel encoder with at least nine parallel channels. Rather they prefer Broadbent's (1958) filter model or Neisser's (1967) preattentive mechanisms for screening out irrelevant features. However, they note that the 5 msec. rate gave a phenomenal impression that all letters were presented simultaneously. According to Liss (personal communication), at low ISIs, before successiveness is perceived, processing is frequently parallel independent. At higher ISIs in this study, it is possible that there was time to process each letter before the next was presented, in serial fashion. Thus, the absence of effect of input rate on ds may have concealed the fact that different processing strategies were being used at different rates.

Aaronson (1968) also found no effect of input rate on detection. In her task, Ss monitored an auditory sequence of digits, responding yes upon hearing a critical digit. The rates of presentation were 6, 3, or 1.5 digits per sec. Only when Ss were required to both monitor and recall the digit sequence, did errors increase as rate of presentation increased. Aaronson suggests that monitoring involves only an early stage of processing which might be termed "sensing", while recall requires both "sensing" and identifying. It may be that sensing is a parallel process, while identifying is a serial process, according to Aaronson. Thus, if only sensing is involved in a search task, then she would seem to agree with Erikson and Spencer (1969) that such tasks cannot discriminate between serial and parallel models of the encoding process itself.

The usefulness of a visual search task in investigating processing strategy has been criticized on other grounds. These are that there is no control over the amount of time each item is stimulating S or over his scanning behavior. Thus, visual processing time cannot be determined independently of decision time (Haber, 1969b). Furthermore, according to Liss and Reeves (1971), when reaction time data indicate serial, parallel dependent, or parallel independent processing, it is uncertain whether all stages of processing can be characterized by the same processing strategy or to which stage (e.g., pre-or post-iconic) a particular strategy applies. These criticisms apply to all tasks which use latency to estimate processing time, in search tasks, as well as same-different judgment tasks.

A better "converging operation" (Garner, Hake, and Eriksen, 1956) than reaction time in both Haber's and Liss's view, is backward masking. Backward masking can precisely control the amount of time S is processing the stimulus, as long as it is assumed that the mask stops processing. This assumption involves a theoretical controversy which will be briefly reviewed.

Interruption Versus Summation Theories of Masking.

As stated in part A, Sperling (1963) assumes that presentation of a masking stimulus after a target stimulus interrupts the processing of the target stimulus. Averbach and Coriell (Averbach and Sperling, 1961) have termed this interruption "erasure" of the original stimulus. There are different versions as to the stage in processing where this interruption occurs. Some investigators (e.g., Haber, 1970a; Sperling, 1963, 1967) maintain that a visual image of the target stimulus is formed but that this image is interrupted before it can be read into a more permanent storage, such as verbal memory. Others (e.g., Liss, 1968) think that the mask stops pre-image processing, i.e., that the interruption occurs after retinal stimulation but prior to the appearance of the image. According to the latter view, "a pre-iconic representation of the mask disrupts an earlier pre-iconic representation of the target, thus stopping the recoding of target information from one pre-iconic stage to another " (Liss and Reeves, 1971, p. 5).

In opposition to interruption theories of masking are summation theories of masking, which maintain that the mask combines with the target stimulus, thereby reducing the target's clarity. Thus, masking effects occur only on a peripheral level during retinal stimulation itself. According to a peripheral or sensory interpretation, a "subsequently masked stimulus is never represented more clearly than that representation available after the mask has had its effects" (Haber, 1969a, p.7). As Haber points out, the distinction between interruption and summation theories of masking has critical consequences for the use of masking as a tool for investigating information extraction.

Much of the controversy between these two theories has revolved around the shape of the obtained masking function. Proponents of a summation theory tend to obtain Type A curves, in which maximum masking is found with simultaneous presentation of target and mask. Masking effects decrease monotonically with increasing delays of the mask, both in a forward and backward direction. In forward or proactive masking, the mask precedes the target; while in backward or retroactive masking, the mask follows the target. Type B curves are functions in which there is little or no masking with simultaneous presentation of target and mask, and masking effects increase to a maximum when the mask is delayed by 50 to 100 msec. Thus, the mask appears to be affecting the target some time after its input, rather than degrading the input itself. Further support for this interpretation is that Type B functions do not show forward masking; masking effects are limited to presentation of a mask after the target.

Type A masking functions are always obtained by Eriksen and his associates (Eriksen, 1966; Eriksen and Collins, 1964; Eriksen and Lappin, 1964; Eriksen and Steffy, 1964; and Eriksen, Collins, and Greenspon, 1967), who are the most vigorous proponents of luminance summation theory. According to Eriksen, masking effects are due to a summation of luminances of the target and masking stimuli, which results in a reduction of contrast between the target stimulus and its background. For example, suppose that the contrast ratio between a black target letter and its background is 1:10 and that the background of the masking stimulus is also equal to 10. If the luminances of the target and masking stimuli are completely summed, the contrast ratio between the target and its background becomes 11:20. Since accuracy of form identification decreases rapidly as the contrast ratio between figure and ground is reduced below 1:3 (Eriksen, 1966), identification of the target should be greatly impaired under these conditions.

Summation theory would predict Type A curves, with maximum masking under simultaneous presentation of target and mask, since summation would be most complete under these conditions. Masking effects would also be expected to diminish as the interval between target and mask is increased, disappearing after about 100 msec. This seems to be the maximum interval over which we can sum luminances (Kahneman, 1968). Masking effects should also be equal in a forward and backward direction, since summation effects are equal in both directions.

Despite convincing evidence in support of a luminance summation-contrast reduction interpretation of masking effects, Type B curves have been frequently obtained (e.g. Kolers, 1962; Weisstein, 1966; Weisstein and Haber, 1965; and Werner, 1935). Kolers has documented the conditions under which Type B curves are obtained in a detection task. They occur when the target and mask are small black forms of equal contrast, size, luminance, and duration, and when these are all of moderate value. When the masking stimulus is stronger than the target stimulus in terms of luminance, duration or contrast, then Type A curves are obtained. Nearness of the borders of masking and target stimuli is also an important factor in obtaining any masking effects at all. The importance of contours in masking effects has also been stressed by Werner (1935). According to Werner, contours must be actively constructed. If the masking stimulus arrives during construction of the target stimulus, it initiates a new contour-process, which absorbs the original one. Contour construction can take 100 msec. or more to complete and is especially vulnerable in its later phases, according to Werner. This explanation of masking is considered by Neisser (1967) to be the most plausible.

In an identification task, the conditions under which Type A and Type B curves are obtained have not been as carefully documented. However, one major difference between the procedures used by Eriksen and Weisstein is that Eriksen uses lower luminance values for the target and masking stimuli than Weisstein. It is possible that with high luminance levels, the target can be read through the ring mask, used by these investigators, when the mask is presented at short delays. At longer delays of the mask, however, the target image or icon may have faded sufficiently so that the mask becomes more effective. At even longer delays, there is time to process the target completely before the ring appears. This is essentially Eriksen and Collins' (1964) explanation of the U-shaped function obtained by Averbach and Coriell (Averbach and Sperling, 1961). It is related to a conclusion drawn by Kahneman (1968) that suppression of the target in a Type B function is never complete.

For masking to be a useful method in studying information processing, it seems essential that the mask suppress the target. A better mask for this purpose would seem to be one which spatially overlaps the target, so that the target cannot be seen through it. Furthermore, as Haber points out, "to study whether a visual noise field 'stops' visual processing, a good mask should be tailor-made to the patterning of the information in the target" (Haber, 1970b, p. 374). In other words, the mask should be composed of stimuli similar to the target, with contours closely overlapping those of the target stimuli. According to Liss (1968), an effective process-stopping mask is one which must be analyzed spatially by the same central mechanisms as those used for the target. The mask then preempts "the mechanism which has formed and maintained the target representation" (Liss and Reeves, 1971, p. 4).

Liss (1968) used this type of mask to determine if backward masking simply reduces the clarity of the target stimulus, as luminance summation theory purports, or if it does, in fact, stop processing after input. He compared the effects of backward masking with two procedures that affect stimulus clarity without affecting processing time. The first involved varying the luminance ratios of the target and mask presented simultaneously. The second involved varying the stimulus duration of the target stimulus presented without a mask.

The target was an array of one to four consonants, and the mask was a matrix of Ns embedded in Os. Liss found that under backward masking, the number of letters correctly identified increased only with increased exposure duration before the mask, or increased processing time, and was independent of the number presented. In the two other conditions, however, the number of letters correctly identified did increase as the number presented increased. In addition, Ss' judgments about the apparent duration, brightness, and texture of the target stimuli were not the same under backward masking as under the other conditions. For example, Ss judged that letters appeared for a briefer time when presented for 70 msec. followed by a mask than when presented for 7 msec. without a mask, although they were brighter in the first case than in the second. Apparent duration, brightness, and texture were all judged to increase with increased processing time before the mask. Liss concludes from these results that backward masking has effects which are not at all like the effects of procedures which simply reduce stimulus clarity. Rather, it seems to stop processing more centrally after input.

These results have been confirmed by other studies in which the effects of varying stimulus duration are compared to the effects of backward masking. Liss and Reeves (1971), using a display of dots as both target and mask, found the number of dots reported under backward to be independent of the number presented and solely determined by processing time. When stimulus duration was varied, however, the number reported increased as the number presented increased.

Haber and Standing (1968) had Ss rate clarity according to a specified scale under both backward masking and varying stimulus duration conditions. Under backward masking, clarity ratings were always higher than recognition accuracy, indicating that even when Ss could see the stimuli clearly, they did not have time to process them. In addition, rated clarity was higher under masked conditions than under low stimulus duration conditions. For masking, the stimulus duration was set at the 75% accuracy level found for each subject without a mask (approximately 40 msec.). Viewing was clearer when this stimulus duration was followed by a mask than under stimulus durations of 20 msec. or less with no masking. These results show again that the two procedures are not equivalent and that "factors that control the initial registration or representation of the stimulus in the nervous system are independent in part from those factors which control processing or extraction of information from that representation" (Haber and Standing, 1968, p. 84).

Final convincing evidence in support of interruption theories of masking is that backward masking can be obtained dichoptically, that is, with the target presented to one eye and the mask presented to the other (e.g., Kietzman, Boyle, and Linsley, 1971). Thus, it seems that backward masking effects cannot be due to peripheral interference, i.e., neuroretinal and photochemical interactions within the eye. Interference must occur more centrally than the optic chiasm. Since interactions between the optic fibers of the two eyes are considered to be minimal in the lateral geniculate, the authors suggest that the interference most probably occurs in the visual cortex. Forward masking was not obtained dichoptically, and thus, its effects are apparently only peripheral.

Thus, it seems clear that backward masking affects central processing. If a spatially overlapping mask is used, however, a Type A curve is obtained, since this type of mask has its maximum effects at short delays. Thus, Type A curves can no longer be interpreted as support for peripheral views of masking and Type B as support for central views of masking.

Processing Time as a Measure of Serial and Parallel Processing

If masking can be used as a tool in investigating information extraction, the next question to be raised is whether or not studies using backward masking can discriminate between serial and parallel processing. Serial processing has been identified with processing smaller inputs in less time than larger inputs; thus, processing time increases as size of input is increased. Parallel processing has been identified with processing different sizes of input in the same amount of time; thus, processing time does not increase as size of input is increased. Defined in this way, parallel processing is viewed as involving operations which are both independent and simultaneous.

Averbach (1963) found serial processing in reporting number of dots when the mask was also a display of dots. Ss' span rose rapidly to 6-7 dots with increased exposure time up to 100 msec., where it reached asymptote. The asymptote was attributed either to a short-term memory limit or to greater difficulty in discriminating larger numbers from each other.

Using a mask of visual noise, Sperling (1963) found serial processing of simultaneous displays of letters. Each additional letter, up to the immediate memory span, required 10 to 15 msec. additional processing time. This finding has been confirmed by Haber (1969a) and by Liss (1968). However, Haber did find that, with practice, S̲s took no longer to identify four letters than one letter. Furthermore, Sperling (1967), after reanalyzing his results in terms of accuracy of report by position in the array, has concluded that they actually show parallel processing. This conclusion is based on the finding that report accuracy at each location increased with increased exposure duration before the mask. In serial processing, it would be expected that the *n*th location would not be reported better than chance until the exposure duration at which the *n*-1th location is reported with maximum accuracy is exceeded. This is provided, of course, that S̲s report locations in the same order on each trial, for example, left to right. Thus, Sperling concludes that letter recognition involves parallel processing, although it appears to be serial because the different locations reach their maximum accuracy at different rates. Rate differences in processing time probably occur for different retinal locations (Eriksen and Spencer, 1969) and have been found for different letters (Stewart and Purcell, 1970).

Weisstein (1966) considers that an increase in processing time as array size is increased is, in itself, ambiguous. It may mean either that the set of operations is repeating itself in turn for additional parts of the array (serial) or that more operations are being performed simultaneously for each part of the array (parallel). However, she feels that a U-shaped (Type B) function indicates a distinct operation or set of operations that is being performed and that measurement of the range of masking for different-sized arrays can point to serial or parallel processing. Both Weisstein (1966) and Eriksen, Collins, and Greenspon (1967) have found that masking effects extend over a wider range for larger arrays. In their tasks, a ring was used both as a masking stimulus and as an indicator of which items to report. Weisstein (1966) has interpreted the increase in masking range with increases in array size as showing that processing is not parallel in this task. However, since her results do not show range increases which are whole multiples of the increases in array size, i.e., the masking range for four-item arrays is not four times the range for single-item arrays, she concludes that processing is not strictly serial either. She surmises that serial processing may have occurred with respect to some features of each item, although processing was not item by item.

The interpretation which Eriksen et al. (1967) give to the increases in masking range for larger arrays is different, however. They point out that for the multiple-stimulus arrays, the ring is both a masking stimulus and an indicator of which item to report, whereas for the single-item arrays, it is only a mask. The difference between the masking functions could then be totally attributable to the effect of a delayed indicator upon a decaying visual trace. This hypothesis was tested by subtracting a single-item masking function from a six-item masking function to obtain a predicted function for indicator delay. A second experiment, using an arrow indicator, yielded a trace decay function which closely fit the predicted curve.

Thus, masking studies, at least with the types of masks indicated, do not seem to have produced results which can unambiguously point to serial or parallel processing. This is true even when parallel processing is defined as involving operations which are both independent and simultaneous. As stated in part B, not all investigators consider both characteristics to be essential to parallel processing. For those who consider independence of operations to be the essence of parallel (e.g., Neisser, 1967), parallel operations do not have to occur simultaneously. Thus, an increase of _n_ times the processing time for a single item with _n_-item arrays would not necessarily indicate serial processing. The increase could be due to independent parallel operations which are applied in series. For those who make a distinction between independence and dependence in parallel processing (e.g., Liss and Reeves, 1971), an increase of _n_ times the processing time for a single item with _n_-item arrays would not necessarily show serial processing either. It could be due to parallel dependent operations which require more time to complete with larger arrays. To distinguish between serial and parallel dependent processing, processing times for the same number of items must be compared across different-sized arrays. For example, Liss (personal communication) compared processing times for two items from two and four-item arrays. On four-item arrays, _S_s were sometimes required to identify all four items and sometimes only two. The stimulus items were pairs of dots which varied in orientation, i.e., each pair was either vertical or horizontal. Liss found that processing time for two items was faster when there were only two items in the array than when there were four items. Processing time for _two_ items under the four-item condition did not differ as a function of whether _S_s had to report only two items or all four items. This is evidence for parallel dependent processing.

In the research to be reported, the view was adopted that operations must occur simultaneously to be considered parallel but that they did not have to occur independently. Thus, it was considered necessary to distinguish between parallel independent and parallel dependent operations in processing.

Theoretical Rationale for Research and Hypotheses

The purpose of the research to be reported was to investigate the question of whether or not the smaller short-term memory capacity of preschool children as compared to adults (Haith et al., 1970) can be attributed to a difference in processing strategy or simply to a difference in processing speed. The tasks employed by Haith and his associates, i.e., the short-term memory task, the visual search task, and the partial report task, did not permit exact determination of the time needed to identify each item nor of the strategy used by different-aged _S_s. Other research reported (e.g., Gibson and Yonas, 1966; Yonas and Gibson, 1967; Yonas, 1969; and Bracey, 1970) has shown quantitative differences but little qualitative difference between the processing of elementary school children and adults in search tasks. However, the drawbacks of using search latency to determine processing time and strategy have been discussed. In addition, comparison between preschool children and adults would seem to be essential, since the research which has been conducted points to more dramatic differences between these age groups.

The question, then, of whether greater information pick-up with age involves qualitative changes in strategy or simply quantitative changes in rate of processing is still an open one. Gibson (1966) appears to favor a quantitative view, although she feels that optimal strategies for different tasks and different sets of stimuli change with age because of perceptual learning. Apparently, she does not view a change in strategy as a qualitative change. In addition to changes to strategy, she points to an increased ability to select relevant information and shut out irrelevant noise.

Ability to select auditory information has been found to increase between preschool and elementary school years (Maccoby and Konrad, 1966). With respect to visual information, presented tachistoscopically, Maccoby (1966) points out that "there is a period of time, including both the stimulation period itself and the trace period which follows it, during which the perceiver can select those portions of the stimulus display that are most informative or most relevant to his task" (p. 69). Thus, age differences might be expected in this period of selectivity. In a tachistoscopic task, selectivity can occur in the very choice of first fixation. Piaget and Vinh-Bang (Piaget, 1969) have shown that "a young child fixates at random on a figure, but an adult chooses the point of centration from which he will obtain the maximum amount of information, or number of encounters, with a minimum loss of information"(p. 137).

Piaget (1969) stresses qualitative changes in perceptual development, primarily due to replacement of centration by decentration as a mode of viewing. He invokes the single mechanism of decentration to explain age differences in both Type I, primary illusions (e.g., Delboeuf and Mueller-Lyer), which decrease with age, and Type II, secondary illusions (e.g., size-weight and Usnadze), which increase with age. However, Pollack (1968) views these two phenomena as representing two distinct processes. Type I phenomena are nondevelopmental in that they are due to reduced receptor sensitivity with physiological aging. Type II phenomena are developmental in that age changes are related to qualitative changes in cognitive abilities, such as decentration.

The mechanism of decentration, however, is not relevant to tachistoscopic exposures which are too short to permit eye movements. Perception under these conditions is limited to what Piaget terms primary field effects, the "quasi-simultaneous interaction of elements perceived together in one single field of centration without the involvement of a displacement of fixation" (Piaget, 1969, p. 3). Decentration is defined as the co-ordination of centrations and thus, more than one centration or fixation is required. Age differences in decentration, then, cannot predict age differences in performance under tachistoscopic conditions. However, it is possible that they might be predicted from indirect evidence (Piaget, 1969) that the number of encounters involved in a single centration increases with age, as well as the range of their distribution. Encounters are "hits" between stimulus units and receptor units. Unfortunately, they are not directly measurable. However, if Piaget predicts an increase with age in the number of stimulus units sampled during a single fixation, then he might also predict an increase in parallel processing with age.

An increase in parallel processing with age might also be predicted from age differences which have been found in what Triesman (1969) calls "divided attention" tasks. For example, Inglis and Sykes (1967) found that preschool children were unable to report both messages in a dichotic listening task, while older children could report both messages. They attributed the age difference to a difference in short-term memory, but it may be that the preschoolers never attended the second message at all.

Thus, a developmental trend toward increased parallel processing might be predicted from both probabilistic views of perception (Piaget, 1969) and from divided attention studies. In addition, a developmental trend toward increased ability to process selectively would also be predicted from studies of selective attention.

The research to be reported tested both of these predictions. Preschool children, elementary school children, and college students were shown arrays varying in size which were followed by a masking array at varied intervals, to control processing time. Ss were required to identify all of the items in the arrays or to select only part of an array. It was hypothesized that processing time for the first item would not differ with age but that the time needed to identify all subsequent items would decrease with age. It was predicted that this decrease with age would be attributable to an increase in parallel processing. Furthermore, even greater age differences in processing time were expected under conditions of selective processing.

It was hypothesized that adults would show parallel dependent processing, in light of the results obtained by Liss (see part G). This prediction also follows Sperling's (1967) position and differs from Neisser's (1967) view that attentive processing is serial.

Processing time for the same number of items (i.e., two) was expected to be the same for adults under selectivity conditions (two items out of four to be reported) as under full report conditions (all four items to be reported). Thus, Ss were expected to be unable to restrict their processing of extraneous items to a preattentive level. This prediction, again, is based on the results obtained by Liss and is opposed to Neisser's sequential model.

CHAPTER II

METHOD

Design

Subjects of three different age groups were given four stimulus array conditions: 1) one item shown with one to be reported, 2) two items shown with two to be reported, 3) four items shown with two to be reported, and 4) four items shown with four to be reported. The stimulus conditions were administered at seven interstimulus intervals between presentation of the target stimulus array and presentation of a masking array. The intervals were 0, 15, 30, 60, 90, 150, and 250 msec. There were six trials at each interstimulus interval for each stimulus array condition, and the six trials were administered as a block. There were thus 28 blocks of six trials each, for a total of 168 trials. In addition, for each of the three multiple-stimulus array conditions, there was a block of six trials in which no masking array was presented. It is a repeated measures design in which every S in each age group received all 31 blocks of trials, or six trials under every stimulus array condition at each ISI. The dependent variable was the average number of stimulus items correctly identified in each block of six trials.

Subjects

Three groups of subjects, with six Ss in each group, were tested: preschool children, elementary school children, and college students. All Ss were seen at the Lexington School for the Deaf in Queens, N.Y.,but all Ss were hearing. The preschool children were recruited from the neighborhood surrounding the school. Five preschool Ss attended a park nursery school in the area, and the sixth attended a cooperative nursery school. The preschool Ss ranged in age from 4:6 years to 4:10 years, with a mean age of 4:8 years. One other child was dropped because of persistent illness. The elementary school children were obtained from a parochial school which most of the children in the neighborhood attended. All were in the same third grade class. They ranged in age from 8:5 years to 8:10 years, with a mean age of 8:7 years. The adult Ss were college students ranging in age from 19:7 years to 21:10 years, with a mean of 20:9 years. Only female Ss were tested to eliminate possible variance related to sex in parallel processing tasks (Guttentag, 1971). One preschool S was black. Ss were paid for their participation.

Apparatus

A Gerbrands three-field tachistoscope was used in conjunction with a six-channel digital solid state timer, adjustable from 1 msec. to 9900 msec., and a three-channel lamp driver equipped with intensity control. The three fields of the tachistoscope contained the fixation point, the target array, and the masking array,respectively. Channels one, three and five of the timer controlled the duration of the three fields. Channels two, four, and six of the timer controlled the time intervals between the fields. The luminance of the three fields was approximately 2.6 millilamberts for the fixation field, 3.0 millilamberts for the target field, and 3.5 millilamberts for the masking field, as measured by a Macbeth Illuminometer. The intervals between presentation of the fields were dark.

Materials

The stimuli were 4" x 6" cards containing one, two, or four forms outlined in ink. As in the first study of Haith et al.(1970), the size of each form was approximately 8 mm., subtending a visual angle of 33' at the field-subject distance of 81.3 cm. Each form was drawn 33' above, below, to the left, or to the right of center. This circular arrangement, besides corresponding to that used in the Haith study, has the advantage of controlling for variations in sensitivity on the fovea (Eriksen and Spencer, 1969), as well as for variations in masking effects by retinal location (Stewart and Purcell, 1970). All of the stimulus information was contained within $\pm$ 1.5° of the center of the field. For cards containing one item, the form was drawn either above or below the center. For cards containing two items, the forms appeared above and below the center. For cards containing four items, the forms were drawn to the left and right of center, as well as above and below. For the four-item condition in which only two items were to be reported, the two items reported were those above and below the center.

The stimulus set contained twelve forms: square, circle, triangle, thin rectangle, arrow, plus sign, half moon, star, stairs, and three forms resembling a spoon, a boat, and a three-leaf clover. The masking stimulus combined the circle, square, rectangle, and part of the arrow. The forms are shown in Figure 1 in their actual size. At the bottom of Figure 1 is the masking stimulus. The masking array always contained four masking stimuli placed in the four possible stimulus positions: above, below, to the left, and to the right of center. A response card containing all twelve forms, displayed as in Figure 1, was mounted to the right of the T-scope viewer. This procedure is recommended by Haith and his associates so that the child does not have to change his spatial orientation in responding.

For the one item arrays, the form appeared three times above and three times below the center in random order in each block of six trials. Forms were randomly assigned to trials with the constraint that no form be repeated within a single block. Forms were equated for frequency of occurrence in each position across all trials as closely as possible. For two-item arrays, forms were randomly assigned to the above and below positions with the restrictions that 1) each form appear once in each block of six trials, 2) no pair combination be repeated across all trials, and 3) each form appear four times in both positions across all eight blocks of trials. For the four-item arrays, forms were randomly assigned to position with the restrictions that 1) each form appear twice in each block of six trials, once either above or below center and once to the left or right; 2) no form be repeated within an array and no combination of four forms be repeated across all trials; 3) each form appear four times in each of the four positions across all eight blocks of trials.

Procedure

Practice Session

The purpose of the practice session was 1) to provide practice under all four stimulus array conditions, with and without the masking array, and 2) to determine if the stimulus durations to be used for each age group were optimal for every _S_ within that age group. The practice session was begun by _E_ pointing to each form on the response card, without naming it. _E_ told _S_ that these were the pictures she would see in the viewer. _E_ then placed a card containing one item above the response card and asked S to find the picture on the response card below. A second trial without the T-scope was given with another one-item card. E then instructed S that when she looked into the viewer, the first thing she would see would be a dot,and then she would see a picture. E held up the two practice one-item cards on which one form was above center and the other below center. E explained that when there was only one picture on the card, it would sometimes be above the dot and sometimes below the dot. S was always to look at the dot, and then her eyes would be in the right place to see the picture,no matter where the picture was. S was warned not to try to guess where the picture would be but to just put her eyes on the dot first. After she saw the dot and the picture, S was instructed to point to the picture she had seen on the big card. Four tachistoscopic trials with four different one-item cards, two above and two below center, were then administered, using a stimulus duration of 150 msec. and no mask. Any trial on which S made an error was re-administered until S made the correct response. Two-item arrays were introduced in the same way. Two cards were presented without the T-scope. S was told that when there were two pictures, one would always be above the dot and one below. S was to put her eyes on the dot, and then they would be in the right place to see both pictures. A series of two-item pairs was then administered tachistoscopically at a stimulus duration of 150 msec without a mask. If S did not get both items correct on the first four trials, she was given another four trials. Again, if she did not get both items correct on all trials, she was given a third set of four trials. Stimulus duration was then varied in a fast set of descending and ascending trials. Two trials each were given at durations of 45, 30, and 15 msec. If performance was not perfect at 15 msec., an ascending series of two trials each at 15, 30, and 45 msec. was administered. Four-item arrays were then presented. Two trials were given without the T-scope, and S was told that when there were four pictures, they would be above and below the dot and also on the sides. Four tachistoscopic trials were then administered, using a stimulus duration of 150 msec. without a mask, followed by the same descending and ascending series described for two-item arrays. The descending and ascending series of trials for two and four-item arrays confirmed the pilot findings that a 15 msec. stimulus duration was sufficient for optimal performance for every adult and eight-year-old tested, while a 30 msec. duration was needed for four-year-olds.

The second part of the practice session tested these stimulus durations for each age group at the shortest and longest ISIs before presentation of the masking array, 0 and 250 msec. The purpose of this part was to give practice trials with the mask and to see if the ISI range was wide enough to provide complete data for each age group. Specifically, it determined if Ss of all age groups were able to get less than one item correct at 0 msec. ISI and reach their maximum number correct, as indicated on no masking trials, at 250 msec. ISI, given the stimulus duration set for each age group. Nine trials were given under each stimulus array condition: one item, two items, four items with four to be reported, and four items with two to be reported. The first three trials presented the mask at 300 msec. after the target array, the next three at 250 msec., and the last three at 0 msec. In addition, the last condition, four items with only two to be reported, was introduced by two practice trials without the T-scope, followed by six practice trials in which no mask was presented. Four-year-olds were given the second part of the practice session in a separate session.

During practice trials, feedback was given, and incorrect responses were corrected. Four-year-olds were rewarded for correct responses with checkers which were piled on top of the T-scope. The checkers were exchanged for M & Ms during breaks in the session. To somewhat equate amount of reward across stimulus array conditions, the children had to get at least two items correct on the four-item, report four, arrays to win a checker. This was not difficult, since one correct response was expected by chance on the four-item arrays. Eight-year-olds and adults were given verbal reinforcement.

Ss of all ages were given the same instructions and received the same number of practice trials, with the exceptions noted. To minimize failure, all Ss were told that there would be times when no one could see all the pictures, or even any of them. They were told to point to the pictures they actually saw first and then to guess. The concept of guessing was carefully explained to the four-year-olds. Ss were always required to give the same number of responses as there were items in the array. Some four-year-olds, who showed a strong tendency on four item arrays to point along a row or column or in a square on the response card, were encouraged not to do this. One four-year-old, who did not understand the words above and below, received additional trials on the four-item, report two, condition until she understood which items she was to report.

Test Sessions

Each test session was introduced by some additional practice trials. One practice card from each stimulus array condition was presented in the T-scope, followed by the masking array. The ISI between the target array and the mask was decreased from a point where S could clearly see the stimuli

(300 msec.) to a point where she could see nothing or to 0 and then increased to maximum clarity again. Test trials were then administered.

Test trials consisted of a block of six trials under each of the four stimulus array conditions at seven ISIs between target and mask, plus three no masking blocks under the three multiple-stimulus array conditions, for a total of 31 blocks of trials. The order of stimulus array conditions across the 31 blocks of trials was randomized, with the constraint that there be at least one block under every condition in every seven blocks of trials. All Ss received the same random order of stimulus array conditions. The order of ISI was randomized separately for every S, with the constraint that, insofar as possible, each ISI appear once in every eight blocks of trials. The 31 blocks of test trials were distributed over four or five sessions for the four-year-olds, three sessions for eight-year-olds, and two sessions for adults. Four-year-olds and eight-year olds were seen twice a week with at least one intervening day. The two adult sessions were from six days to two weeks apart.

Each block of test trials was introduced by a practice card to demonstrate the stimulus array condition without the T-scope. A standard card, made up of forms not included in the stimulus set, was then cycled five times at the ISI for that block. Thus, S knew before each block both the stimulus array condition and the ISI for that block. The six test trials for that block were then administered. Four-year-olds were reminded of the stimulus condition before every trial and told to look at the dot first.

A test trial sequence is diagrammed in Figure 2. S was told to put her eyes inside the black viewing mask of the T-scope. E then said "ready", and the fixation field was shown for 750 msec. This fixation time is recommended for preschoolers by Haith et al. (1970). The fixation field was followed by a dark interval of 100 msec. The target array then appeared for 15 msec., for adults and eight-year-olds, or 30 msec., for four-year-olds. The target array was followed by a dark interval of variable length. The masking array was then presented for 100 msec. S was instructed to respond after she saw the mask by pointing on the response card to the pictures she had seen before the mask. For children, the mask was called the funny card, and for adults, it was called the third card.

Responses were recorded in order by E. All S were told how many they had correct on every trial. Incorrect responses were no longer corrected. However, on the four-item, report two, condition, Ss were told if they reported an item on the side and reminded to report only the top and bottom items. Four-year-olds continued to receive checkers for correct responses, and again, they had to get at least two items correct on the four, report four, condition to win a checker. The checkers were exchanged for M & Ms during breaks in the session.

At the completion of all test sessions, Ss were asked to name each form on the response card. They were then asked a series of questions concerning 1) which forms were easiest and most difficult for them or which forms they liked and did not like, 2) which forms they confused easily, 3) whether some forms were easier to guess than others because they could see parts of them, 4) when it was easiest to see one and two items (under which condition), 5) how many forms they thought they could see at once under each condition when the speed was both fast and slow, 6) which position in the stimulus array was easiest, next easiest, etc., 7) whether in any condition they reported items according to their positions on the stimulus array, i.e., top first, left next, etc., 8) whether they reported the forms they really saw first and then guessed, or vice versa, and

9) what they did to remember the forms after they saw them until they pointed, i.e., whether they named the forms, or whether they just remembered what the forms looked like, and whether they rehearsed.

CHAPTER III

RESULTS

The mean number of correct responses for each block of trials was corrected for chance guessing before analysis (see Appendix A). The corrected means for each age group are given in Table 1. Two separate analyses of variance were performed on the corrected means. The first compared the means for conditions one, two, and four, under which all items were to be reported. The second compared the means for conditions two and three and the first two items reported under condition four. The corrected means for the second analysis are presented in Table 2. The purpose of the first analysis was to look at the effect of increasing array size upon the mean number of forms reported at each ISI by each age group. The purpose of the second analysis was to look at the effect of varying stimulus condition upon report of two items only, for each age group. A third analysis compared accuracy of the first and second responses under conditions two, three, and four, for each age group.

Array Size and Whole Report

A 3 x 3 x 7 analysis of variance included age as a between-subject variable and array size and interstimulus interval as within-subject variables. The results of this analysis are given in Table 3. As expected, the main effects of age, array size, and ISI were all highly significant, indicating that higher scores were obtained with increasing age, array size, and ISI. However, the increases in score with increasing array size and ISI were not uniform across all age groups, as indicated by significant age x array size and age x ISI interactions. Figure 3 shows the effect of increasing array size and ISI at each age level separately. The age x array size interaction, with means combined across ISI levels, is presented graphically in Figure 4. The age x ISI interaction, with means combined across levels of array size, is presented graphically in Figure 5. Comparison of means using the Tukey (a) procedure (Winer, 1962, p. 87) showed that the age x array size interaction was due to the fact that the age groups did not differ in accuracy on the single-item arrays but did differ significantly on the larger arrays. All groups showed a significant increase in scores as array size was increased from one to two items ($p < .01$), but the increase for four-year-olds was relatively less than for older S̲s. Thus, their score on two-item arrays was significantly less than that of adults ($p < .01$) and eight-year-olds ($p < .05$). Only eight-year-olds and adults showed significant increases in scores as array size was increased from two to four items ($p < .01$), and, thus, they significantly outperformed four-year-olds on four-item arrays also ($p < .01$). In fact, four-year-olds showed a significant decrease in scores as array size was increased from two to four items ($p < .05$). Adults and eight-year-olds did not differ significantly in their scores on any array size, although adults did obtain slightly higher scores on the four-item arrays.

The age x ISI interaction is attributable to the fact that the curves for the age groups begin to diverge significantly after 15 msec. The groups did not differ in accuracy at 0 and 15 msec., although both groups of children scored somewhat above adults at 0 msec. and eight-year-olds continued to score slightly higher than adults at 15 msec. By 30 msec., adults began to significantly outperform four-year-olds ($p < .05$), while eight-year-olds did not score significantly above four-year-olds until 60 msec. ($p < .05$). Both older age groups continued to show significantly higher scores than four-year-olds at all longer ISIs ($p < .01$). Adults and eight-year-olds did not differ at any ISI.

The age x ISI interaction is also due to the fact that significant increases in scores were found between 0 and 15 msec. ISIs for adults alone ($p < .01$) and between 30 and 60 msec. ISIs for adults ($p < .01$) and eight-year-olds ($p < .05$).

The array size x ISI interaction was also significant. This interaction, with the means combined across age groups, is depicted graphically in Figure 6. Significantly higher scores were obtained on two-item arrays than on single-item arrays at ISIs of 30 msec. and longer ($p < .01$). The means for four-item arrays were significantly higher than the means for single-item arrays at all ISIs ($p < .01$). Four-item arrays did not differ from two-item arrays except at 15 msec. ISI ($p < .01$). However, this is a result of averaging across age groups, since four-year-olds scored higher on two-item arrays than on four-item arrays, while the reverse was true for older *S*s. The difference between the two and four-item arrays at 15 msec. is due to the fact that this is the only ISI at which four-year-olds scored higher on the four-item arrays.

The three-way interaction between age, array size, and ISI was not significant.

Examination of the means in the first three columns of Table 1 can further clarify these results. The following can be observed: a) Age groups did not differ much in processing time for one item from one, two, or four-item arrays. They reached a minimum accuracy level of 70% correct at about the same ISI. For one-item arrays, this ISI was 60 msec.; for two-item arrays, it was 30 msec. (eight-year-olds were somewhat faster); and for four-item arrays, it was 15 msec. Thus, for all age groups, processing time for one item decreased as array size increased. b) Age groups did differ in processing time for the second item. On two-item arrays, eight-year-olds and adults reached a 70% accuracy level at 90 msec., while four-year-olds did not approach this accuracy level until 250 msec. On four-item arrays, four-year-olds did not attain 70% accuracy on the second item. Adults reached 70% accuracy at 60 msec., while eight-year-olds reached it at 90 msec. Thus, for adults, processing time for the second item, as well as for the first, decreased as array size increased. For eight-year-olds, the second item was processed equally fast from two and four-item arrays. For four-year-olds, it was processed more slowly from four-item arrays than from two-item arrays. c) Age groups differed in asymptotic level. Four-year-olds reached an asymptote of 1.7 items on two-item arrays, while eight-year-olds attained a level of 1.9 accuracy and adults almost perfect accuracy. On four-item arrays, four-year-olds reached an asymptote of only 1.4 items, without the mask, while eight-year-olds reached a maximum of 2.3 items and adults a maximum of 2.6 items. d) Age groups differed in relative number of items processed at each ISI from different array sizes. At each ISI, four-year-olds processed somewhat more from two-item arrays than from one-item arrays, but not twice as much. They processed less from four-item arrays than from two-item arrays, except at 0 and 15 msec. Eight-year-olds processed about twice as much at each ISI from two-item arrays as from one-item arrays. They processed slightly more from four than from two-item arrays between 0 and 30 msec., about the same at 60 and 90 msec. and somewhat more again from four-item arrays at longer ISIs. Adults also processed twice as much from two-item arrays as compared to one-item arrays at all ISIs. They processed slightly more from four than from two-item arrays at all ISIs.

In summary, this analysis indicates that four-year-olds do as well as eight-year-olds and adults in processing single-item arrays and in processing one item from multiple-stimulus arrays. However, they are not as good at processing subsequent items, and, thus, their performance on two and four-item arrays is worse than that of older _S_s. They can process a second item at almost 70% accuracy if there are only two items, but they get less than one and a half items if there are more than two items in the array. Eight-year-olds show a maximum capacity of slightly less and adults of slightly more than two and a half items. With scores averaged across array sizes, four-year-olds begin to process less than adults at 30 msec. ISI and less than eight-year-olds at 60 msec. ISI. Eight-year-olds process as much as adults at all ISIs. With scores averaged across age groups, more is processed from four-item arrays than from one-item arrays at all ISIs and more from two-item arrays than from one-item arrays at ISIs of 30 msec. and longer. About the same number of items is processed from the two and four-item arrays at every ISI, with the exception of 15 msec. However, four-year-olds actually process less from four-item arrays than from two, except at 15 msec., while older Ss process more from four-item arrays than from two at most ISIs.

Array Condition and Report of the First Two Items

A 3 x 3 x 8 analysis of variance included age as a between-subject variable and array condition and interstimulus interval as within-subject variables. The array conditions were two items, four items with two to be reported, and four items with four to be reported. Only the first two items reported under the last condition were included in the analysis. The block mean scores for this analysis are given in Table 2, and the results are presented in Table 4. Again, all main effects and two-way interactions were significant, but the three-way interaction did not attain significance.

Figure 7 shows the effect of array condition and ISI at each age level separately. Figure 8 presents a graph of the age x array condition interaction. Comparison of means using a Tukey (a) procedure showed that four-year-olds had significantly lower scores than adults ($p < .01$) and eight-year-olds ($p < .05$) under all three conditions, while the older age groups did not differ from each other. The reliable interaction is due to the fact that only four-year-olds showed a significant drop from condition two (two items) to condition four (four items, report four) ($p < .01$), that only four-year-olds and adults showed a significant drop from condition two (two items) to condition three (four, report two) ($p < .01$), and that only adults showed a significant drop from condition four (four, report four) to condition three (four, report two) ($p < 01$).

Eight-year-olds' scores did not differ significantly under the three conditions. Thus, for four-year-olds,processing of two items was much easier when there were only two items presented than when four items were presented. Four-item arrays were equally difficult when any two items were reported as when two specific items were reported. For adults, report of two specific items out of four was much more difficult than either report of two items out of two or any two items out of four. Eight-year-olds, as can be seen in Figure 8, do slightly better than adults on condition three and slightly worse on condition four. Thus, their mean scores are closer under the three conditions.

The age x ISI significant interaction found in the first analysis was replicated. Figure 9 shows that four-year-olds' and eight-year-olds' scores were somewhat above those of adults at 0 msec., and eight-year-olds continued to do slightly better than adults at 15 and 30 msec. However, these differences, though more pronounced than in the first analysis, are not significant. Eight-year-olds began to outperform four-year-olds at 15 msec. ($p < .05$), while adults' scores did not differ from those of four-year-olds until 60 msec. ($p < .01$). Eight-year-olds and adults did not differ significantly in their scores at any ISI.

The age x ISI interaction is also due to the fact that only four-year-olds showed a significant increase in scores between the longest ISI, 250 msec., and the no masking condition ($p < .05$). Eight-year-olds' scores increased significantly between 60 and 90 msec. ISI ($p < .05$), and adults' scores increased significantly between 0 and 15 msec. ISI ($p < .05$) and between 30 and 60 msec. ISI ($p < .01$).

The array condition x ISI interaction is shown graphically in Figure 10. With one exception, no differences were found between conditions at the shortest ISIs, 0 to 30 msec., at the longest ISI, 250 msec., or under no masking. The exception was that scores under condition four (four, report four) were significantly higher than under condition three (four, report two) at 15 msec. (p .05). At middle ISIs of 60 to 150 msec., scores under condition two were significantly higher than scores under condition three (p .01). Condition four was significantly superior to condition three only at 90 msec. (p .05). No significant difference between conditions two and four was found at any ISI.

Examination of the means in Table 2 shows that under condition three (four items, report two), four-year-olds processed the first item above 70% accuracy only on no masking trials. When only the first two responses of condition four (four items, report four) are included in the analysis, the first item was not processed above 70% accuracy until 90 msec. This is in contrast to 15 msec. when all four responses are included, although a stable level of high accuracy was not actually attained until 60 msec. (see Table 1). Under condition three, four-year-olds processed the second item only on no masking trials and only to a level of approximately 20% accuracy. They reached about the same accuracy level for the second item under condition four when only the first two responses are included in the means. In contrast, when all four responses of condition four are included in the means, Table 1 indicates that four-year-olds began to process the second item at 150 msec. and reached an accuracy level of between 40% and 50% under no masking. Thus, the means demonstrate clearly that four-year-olds processed the first item faster under condition four than under condition three, even when only the first two responses of condition four are included. Processing of the second item did not differ under the two conditions, however. Processing of both items was much slower than under condition two. At each ISI, except 0, Table 2 shows that four-year-olds processed more under condition two than under condition three. At all ISIs, except 15 msec., more was processed under condition two than four. Furthermore, despite the fact that overall mean scores on conditions three and four did not differ significantly for four-year-olds, they processed more under condition four than three at all ISIs except 15 msec.

Eight-year-olds processed the first item at 70% accuracy under condition three (four, report two) at 30 msec., as compared to 15 msec. under both condition two and four (first two items of four, report four). Their speed of processing the second item was also slower under condition three (250 msec.) than under conditions two (90 msec.) or four (150 msec.). Adults did not process one item in condition three until 60 msec., slightly slower than eight-year-olds, but they were the same on the second item (250 msec.) Adult speed of processing the first item was also slower under condition three than under condition two (30 msec.) or four (15 msec.). Similarly, their speed of processing the second item was slower under condition three(250 msec.) than under conditions two or four (90 msec.). For both groups, processing time for the first item was the same when only the first two items of condition four were included as when all four responses were included (15 msec.). However, processing of the second item was slower when only the first two responses were included. Thus, this analysis, unlike the previous analysis, does not show an increase in items processed at each ISI from condition two to condition four. Rather, Table 2 shows that eight-year-olds and adults got about the same mean number correct on two-item and four-item arrays at most ISIs, except 0, 60, and 90 msec. for eight-year-olds and 15 msec. for adults. Both groups processed less under condition three than either condition two or four at all ISIs up to 250 msec., except for 0 msec. for eight-year-olds.

In summary, this analysis indicates that all age groups had difficulty restricting their processing to two specific items out of four, such that processing in this condition was slower than when they were shown only two items or when they could report any two items out of four. The comparison between condition two and three was significant for only four-year-olds and adults, however, while the comparison between conditions three and four was significant only for adults. Four-year-olds did not differ on conditions three and four, because their performance on condition four, when only the first two items were included, was somewhat depressed. Eight-year-olds showed the same trends as adults, although their means under condition three were not significantly lower than under conditions two and four.

Order of Report

A 3 x 2 x 3 x 8 analysis of variance was performed on the mean number of first responses correct and the mean number of second responses correct, on each block of trials. The between-subject variable was age, and within subject variables were report position, array condition, and ISI. The results of this analysis are given in Table 5. All main effects were highly significant, as well as the age x array condition, age x ISI, and array condition x ISI interactions found in the previous analyses. In addition, order of report interacted significantly with age, with ISI, with age x ISI, and with array condition x ISI.

The three-way interaction between age, report position, and ISI, with means combined across array conditions, is depicted in Figure 11. Comparison of means using the Tukey (a) procedure showed that R1 was significantly more accurate than R2 at all ISIs for both four-year-olds ($p < .01$) and eight-year-olds ($p < .05$). For adults, R1 was more accurate except at ISIs of 0 and 250 msec. and under no masking ($p < .01$). It is clear from Figure 11, however, that the difference between R1 and R2 is much larger for four-year-olds than for older *S*s. Four-year-olds' R2, averaged across array conditions, never surpassed 50% accuracy, whereas the R2 of older *S*s, as well as R1 of all *S*s, reached at least 80% accuracy. Figure 11 also shows abrupt increases in accuracy of R1 between 0 and 15 msec. for eight-year-olds and adults, between 30 and 60 msec. for adults, and between 250 and no masking for four-year-olds. These increases were significant by a Tukey test ($p < .05$). Thus, R1 accuracy for older *S*s increased abruptly with increases at the shortest ISIs, while for four-year-olds, the significant increase occurred when the mask was removed. Accuracy of R2 showed significant increases between 30 and 60 msec. for adults and between 60 and 90 msec. for eight-year-olds ($p < .01$) but no significant increases for four-year-olds.

The age x report position x ISI interaction is also due to the fact that the age curves for R1 cross over between 0 and 60 msec. At 0 msec., the R1 of four-year-olds was significantly higher in accuracy than the R1 of adults ($p<.01$). The R1 of eight-year-olds was also above adults at 0 msec. but not significantly, nor did it differ significantly from the R1 of four-year-olds. At 15 msec., there was no longer a difference between the R1 accuracy of four-year-olds and adults. At 30 msec., the R1 of eight-year-olds became significantly higher than the R1 of four-year-olds (p .01), while adults' R1 was not superior to the R1 of four-year-olds until 60 msec. ($p<.01$). Both older age groups continued to outperform four-year-olds in R1 at longer ISIs, until the no masking condition,in which there was no longer a difference between groups. Eight-year-olds and adults did not differ in R1 at any ISI. For R2, there was no difference between groups between 0 and 30 msec. ISI. At 60 msec., R2 of four-year-olds became significantly lower than the R2 of both older age groups ($p<.01$), and this difference was found at all longer ISIs and under no masking. There were no differences between the R2 of eight-year-olds and adults at any ISI. Thus, the finding of previous analyses that there is a crossover between 0 and 30 msec., with children outperforming adults at 0 and adult accuracy rising to equal children's performance at 15 and surpass it between 30 and 60 msec., occurs only for R1. The effect is significant only between four-year-olds and adults, however.

The report position x array condition x ISI interaction is depicted in Figure 12. R1, averaged across all age groups, was significantly higher than R2 at the middle ISIs of 60 to 150 msec., under all array conditions ($p < .05$). In addition, it was significantly higher at the lowest ISIs, 0 to 30 msec. under condition two ($p < .05$), but only at 30 msec. under condition three ($p < .01$) and 15 msec. under condition four ($p < .01$). R1-R2 differences at the longest ISI, 250 msec., and under no masking were found only under condition four ($p < .05$).

In terms of relative performance under each condition on R1 and R2, condition two was significantly higher than condition three on R1 at ISIs of 30 and 90 msec. ($p < .01$) and on R2 at ISIs of 60 to 150 msec. ($p < .01$). Condition four was higher than three on R1 at 15 msec. ($p < .01$) and on R2 at 60 msec. ($p < .05$). There were no significant differences between conditions two and four at any ISI for either R1 or R2. Thus, significant differences between conditions two and three are found only at middle ISIs, where Ss of all age groups reached a high degree of accuracy on R1 under condition two (30 msec.), began to process R2 under condition two (60 msec. for older Ss; 150 msec. for four-year-olds) and attained a high degree of accuracy on R2 under condition two (90 msec. for older Ss). Significant differences between conditions four and three are found only for those ISIs where older Ss began to process R1 under condition four (15 msec.) and R2 under condition four (60 msec.).

In summary, this analysis shows that all age groups did better on their first than their second response at almost all ISIs. However, the R1-R2 decrement was much greater for four-year-olds. Furthermore, older Ss showed significant increases in R1 accuracy with increases at shorter ISIs, while four-year-olds' R1 accuracy increased significantly only between 250 msec. and no masking. However, at 0 msec., R1 accuracy was higher for four-year-olds than for adults. Since R1 accuracy increased at a faster rate for older Ss with increases at shorter ISIs, they surpassed four-year-olds between 30 and 60 msec.

R1 was more accurate than R2 at all but the longest ISIs under condition two, at middle ISIs under condition three, and at almost all ISIs under condition four. Accuracy under conditions two and four was higher than under condition three generally for those ISIs at which Ss began to process R1 or R2 faster under conditions two and four or where rapid increases in accuracy were found under these conditions with increases in ISI.

Individual Variation Within Age Groups

Four-year-olds

Speed of processing varied considerably in this age group. On single-item arrays, the ISI at which 70% accuracy was attained ranged from 15 msec. to 250 msec. Two-item arrays showed somewhat less variation. The ISI at which 70% accuracy was reached for the first item ranged from 0 to 60 msec. For the second item, it was reached between 150 msec. and no masking, although two Ss attained only 60% accuracy. On four-item arrays, performance was somewhat inconsistent. An accuracy level of 70% on the first item was reached by five Ss between 0 and 15 msec., but their accuracy dropped at some of the longer ISIs. The sixth S attained a consistent 70% accuracy level at 60 msec. ISI. On the second item, two Ss reached an inconsistent 70% accuracy level between 30 and 150 msec., one reached 70% accuracy under no masking, and three did not reach this level. No S had more than an average of 1.8 items correct on the four-item arrays, even under no masking. Inconsistent performance was also found under the four, report two, condition. Three Ss attained 70% accuracy for the first item at 0 msec. but did not reach this level again except at 250 msec. ISI or under no masking. A fourth S reached this level at 150 msec. and under no masking, and the other Ss only under no masking.

Despite the above variations, all Ss except one processed more from two-item arrays than from either single-item arrays or four-item arrays at most ISIs. At the lowest ISIs, between 0 and 30 msec., some Ss processed more from four than from two-item arrays. All Ss did worse on the four item, report two, condition than on either the two item condition or the four, report four, condition, at most ISIs except 0 msec.

Eight-year-olds

For single-item arrays, the ISI at which a consistent level of 70% accuracy was reached ranged from 30 to 90 msec. On two-item arrays, the ISI at which 70% accuracy was reached for the first item ranged between 0 and 60 msec. For the second item, it ranged between 60 and 90 msec., although two Ss did not attain this level consistently until between 150 msec. and no masking. For four-item, report four, arrays, the ISI for 70% accuracy on the first item ranged from 0 to 30 msec. For the second item, a consistent 70% accuracy level was reached between 30 and 90 msec. Two Ss did not get more than two items correct, one attained a 40% accuracy level on the third item at 250 msec. ISI, and two Ss processed three items between 150 msec., 250 msec., and no masking, though not consistently at all these ISIs. The highest accuracy attained by an eight-year-old at any ISI was 3.4 items. For four items, report two, arrays, ISI for 70% accuracy on the first item ranged from 15 to 30 msec., except for one S who did not reach this level until 150 msec. On the second item, it was reached by all Ss between 90 msec. and no masking.

All _S_s processed twice as much from the two-item as from the single-item arrays at most ISIs except 0 and 15 msec. All _S_s but one processed more from four-item arrays than two-item arrays at most ISIs except 60, 90, and 150 msec. At middle ISIs of 30 to 90 msec., most _S_s processed more from the two-item arrays than from the four, report two, arrays. At most ISIs, all _S_s processed more from the four, report four, arrays than from the four, report two, arrays.

Adults

For single-item arrays, the ISI at which 70% accuracy was reached ranged from 30 to 90 msec. For two-item arrays, 70% accuracy was attained between 15 and 30 msec. for all _S_s but one, who did not reach this level until 90 msec. On the second item, it was reached at 60 msec. by all _S_s except the same one, who did not reach this level of accuracy until 250 msec. For four-item arrays, 70% accuracy was reached by all Ss between 0 and 15 msec. on the first item. On the second item, it was reached between 30 and 90 msec. The third item was processed above 50% accuracy between 90 and 250 msec. by all _S_s with the same exception, who did not process more than two items. For the four, report two,arrays, 70% accuracy was reached by all _S_s between 30 and 150 msec. on the first item and between 90 msec. and no masking on the second item.

All _S_s processed twice as much from the two-item arrays as from the single-item arrays at all ISIs with a few exceptions between 0 and 30 msec. They processed more from four-item than from two-item arrays at all ISIs except 0 and 15 msec. Up to 250 msec., all _S_s processed more from two-item arrays than from four, report two,arrays, and at all ISIs, they processed more from four, report four, arrays than from four, report two.

Form Difficulty

Table 6 shows the difficulty of the twelve forms for each age group in terms of the percentage of trials on which each form was missed. The forms are ranked in order from lowest percentage error to highest for each age group. The rankings for the two younger groups appear to be somewhat more in agreement than either is with the ranking for adults. Except for the arrow, which was more difficult for eight-year-olds, relative to the other forms, than it was for four-year-olds, no form differs in its order by more than ±2 when the two rankings are compared. When the rankings for adults and four-year-olds are compared, the circle and star were much easier for four-year-olds, relative to other forms, than for adults, whereas for adults the stairs and the clover were relatively easier. When the rankings of eight-year-olds and adults are compared, the plus sign is found to be relatively easier for eight-year-olds, while the boat, the clover, and the arrow were relatively easier for adults.

However, when the forms are grouped into more general categories, i.e., the four easiest forms, the four forms of medium difficulty, and the four most difficult forms, age differences become very slight. For all three groups, the half moon, the spoon, and the rectangle belong to the easiest category. For adults, the stairs also belongs to this category, while for both groups of children the circle is an easy form. For adults, the circle is of medium difficulty, and for the children, the stairs is of medium difficulty. For all age groups, the star and the boat are of medium difficulty. For children, the plus also belongs to the medium category, while for adults it is one of the most difficult. For adults, the clover is of medium difficulty, while for children it is one of the most difficult. The other three most difficult forms are the same for all age groups: the arrow, the square, and the triangle.

Within each age group, relative form difficulty was fairly consistent across all subjects, with some slight variation. Four-year-olds varied most on the relative ranking of the star, eight-year-olds on the star and the plus, and adults on the plus and the circle.

The percentage of trials on which each form was missed at every interval before the mask is given in Table 7 for adults, in Table 8 for eight-year-olds, and in Table 9 for four-year-olds. These percentages are for all stimulus array conditions combined. Table 7 shows that adults began to process most forms above 50% accuracy between 30 and 60 msec. The half moon was processed somewhat faster and the star somewhat more slowly. Eight-year-olds began to process most forms above 50% accuracy between 30 and 90 msec. The half moon and the stairs were processed faster and the triangle and arrow more slowly. Thus, they show a wider range in ISI for 50% accuracy across forms than adults. Four-year-olds began to process their four easiest forms about 50% accuracy between 0 and 60 msec. Four more difficult forms, the stairs, the boat, the square and the arrow were not processed at 50% accuracy until 150 msec. The star was processed at 50% accuracy only without the mask, and the plus sign, the clover and the triangle did not reach a consistent 50% accuracy level, even under no masking. Thus, four-year-olds show a kind of bimodal distribution, with easy forms processed at the shortest ISIs and more difficult forms at much longer ISIs.

When ISIs for 50% accuracy are compared across age groups, adults are found to process all forms faster than four-year-olds except the half moon and the circle, which they processed more slowly, and the spoon, which they processed at the same ISI. Adults were faster than eight-year-olds on the boat, the clover, the plus sign, the triangle, and the arrow. They were slower on the half moon, the stairs, and the star, and the same on the rectangle, the spoon, the circle, and the square. Eight-year-olds were the same as four-year-olds on the half moon, the spoon, and the arrow and slower on the circle. On all other forms, eight-year-olds were faster than four-year-olds.

Confusions Between Forms

An error was scored as a confusion between the form given as a response and a form in the stimulus array only if all other responses on that trial were correct. Table 10 gives the confusion matrix for adults, Table 11 for eight-year-olds, and Table 12 for four-year-olds. All groups frequently gave the circle as a response for the square and the thin rectangle for the clover. In addition, adults and eight-year-olds gave the circle for the star, while four-year-olds gave the star for the circle. Four-year-olds gave the circle for the clover, the triangle, and the thin rectangle. Eight-year-olds and four-year-olds gave the thin rectangle for the square and the triangle, and eight-year-olds also gave it for the arrow. Adults and eight-year-olds gave the plus sign for the triangle and star, while four-year-olds gave the plus sign for the boat. Adults gave the boat as a response to the square and the triangle. They also gave the triangle for the square and the square for the clover. Eight-year-olds tended to give the star and the stairs for the square. Eight-year-olds and four-year-olds gave the spoon for the arrow.

For all age groups, the square and triangle were among the most frequently confused stimulus forms. In addition, adults and four-year-olds frequently confused the clover with other forms, and adults confused the star. As would be expected, the most confusable stimulus forms are among the most difficult forms, as given in Table 6. Frequently given confusion responses were the circle and thin rectangle, by four-year-olds and eight-year-olds, and the plus sign, by eight-year-olds and adults. These correspond to the most preferred forms for each age group, as shown in Table 13.

Response Bias

Table 13 gives the response preferences of each age group in terms of the relative frequency with which each form was given incorrectly. The forms are listed in rank order from highest percentage, or most preferred, to lowest percentage, or least preferred. Four-year-olds showed a strong preference for the circle, and they also pointed frequently to the rectangle and the star. They tended to avoid the clover. These biases were true for most four-year-olds, except for the preference for the star, which was the result of an extreme bias by one four-year-old S. Eight-year-olds also preferred the rectangle and the circle. Their non-preferred forms, the arrow and the spoon, differed, however, from those of four-year-olds. These biases were found for most Ss in this age group. Adults preferred different forms from children: the plus sign, the stairs, and the boat. The preference for the stairs, however, was the result of an extreme bias by one S and was not typical of the group. Like eight-year-olds, adults avoided the spoon, but they also avoided the half moon. These tendencies were found in most adult Ss.

Comparison of Tables 6 and 13 indicates some correspondence between response bias and form difficulty. At least, the most preferred forms for each age group also tended to be those on which they made the fewest errors. There was less correspondence between non-preferred forms and forms showing the most errors. For example, adults and four-year-olds tended to avoid the half moon, and adults and eight-year-olds avoided the spoon. However, the spoon and the half moon were very easy forms for all age groups.

Report Strategy

The relative frequency with which each position in the stimulus array was reported in each position of the report sequence is given in Table 14, separately for each array condition and each age group. The first percentage given includes incorrect responses for which the stimulus position could be inferred, i.e., when all other responses in the report sequence were correct. The percentage in parentheses is for correct responses only. It can be seen from Table 14 that when two items were reported, whether two or four were shown, eight-year-olds and adults showed a very strong tendency to report the top position first, followed by the bottom position. All eight-year-olds except one showed this tendency under condition two, except at the lowest ISIs. All but one S again showed it under condition three from the middle ISIs on. All adults showed a top-bottom strategy at most ISIs under condition two. Under condition three, all adults except one showed a consistent top-bottom strategy at middle and long ISIs.

The total percentages for four-year-olds indicate that they were not using a consistent strategy under either condition two or condition three. However, the individual tabulations show that one four-year-old did use a top-bottom strategy at most ISIs under both conditions two and three, while three Ss used this strategy under one of the conditions. A bottom-top strategy was also used by two Ss under one of the conditions.

When four items were presented, adults showed some tendency to continue to report the top item first. However, one S showed this tendency only at shorter ISIs and reported the right item first at longer ISIs. Another S showed a consistent tendency to report the right item first at all ISIs. The table also shows some tendency to report the bottom item last. However, in this case, the last item tended to be incorrect. When only correct responses are considered, the right position tended to be reported last, although three Ss often reported the left position last.

Eight-year-olds show the same individual differences as adults. The total percentages show a tendency to report the top item first, but this tendency was exhibited consistently by only three Ss, at least at longer ISIs. Two Ss showed an inconsistent tendency to report the top first, and the sixth reported the right item first and the top second.

A top first strategy on four-item arrays was shown by only one four-year-old at middle and long ISIs. Another four-year-old showed a tendency to report the right item first at the longest ISIs. The other four Ss showed no consistent strategy.

In summary, a consistent report strategy was shown by only the two older groups of Ss when only two items had to be reported. Their strategy then was to report the top item first. When four items had to be reported, Ss varied in their strategies, and most did not use a consistent strategy.

The earlier analysis by order of report indicated that accuracy of the first response was higher for all age groups at all ISIs. Thus, it follows that the top position was more accurately reported, at least under conditions two and three for the two older age groups. It should be noted that a greater accuracy for the top position was not found for the single-item arrays. All Ss of all age groups showed an approximately equal number of items correct in the bottom position as in the top position at most ISIs.

Intrusion Errors

Intrusion errors were those items to the left and right on four-item arrays which were reported by Ss incorrectly under condition three, in which they were to report only the top and bottom items. Table 15 gives the number and percentage of errors which were right intrusions, left intrusions, and other items not in the stimulus array, by ISI and age group. Four-year-olds made approximately the same total number of right intrusions as left intrusions. Eight-year-olds reported slightly more right items incorrectly than left items. Adults showed a strong tendency to report right items more than left items. For four-year-olds, the total number of intrusion errors was about the same at all delays of the mask. Only on no masking trials did the number of intrusion errors decrease. The number of other errors did not substantially decrease even without the mask. For eight-year-olds, the number of intrusion errors and the number of other errors decreased at approximately the same rate as ISI increased. Adults showed the same decrease in other errors with increasing ISI, but they showed an increase in the total number of intrusion errors between 0 and 30 msec. At 0 msec., they made about the same number of intrusion errors as younger Ss, but they made many more other errors, such that their relative percentage of intrusion errors was much less. At 30 msec., they made more intrusion errors than younger Ss. At longer ISIs, their intrusion errors decreased. Thus, at the shortest ISIs, adults made relatively fewer intrusion errors than younger Ss, whereas they made relatively more at longer ISIs.

Subjects' Reports

In all age groups, there were subjects who named all the forms and subjects who did not have names available for some of the forms. The most frequently unnamed forms were the boat, the spoon, and the clover, and these were more abstract forms. For no S was there a consistent relationship between availability of names for forms and form difficulty. In all age groups, some Ss reported using names, some Ss reported using visual images, and some reported doing both. Adult Ss reported that they were unable to name the forms at fast speeds (i.e., at low ISIs) but that they named and rehearsed the forms at slower speeds (i.e., at high ISIs). Ss of all age groups were incorrect about which forms were easiest and which were most difficult, according to their own relative rankings. The forms most often reported as easiest by adults were the simple "basic" geometric forms, such as the square, triangle, circle, plus sign, and rectangle, when, in fact, only the last form was

was an easy form for them. Ss were also incorrect about which positions were easiest to see and the position strategy they had used, except for some Ss on condition two and some adults on the first two positions of condition four. Some eight-year-olds and adults reported that at fast speeds, it was difficult to tell what position a form was in.

Some four-year-olds reported being able to see all forms at once, some that they saw one form at a time, and some that they saw two at once. Most eight-year-olds reported being able to see two forms at once, although for some this was only on four-item arrays. Adults reported being able to see from two to four forms at once on the four-item arrays, at slow speeds, but when they saw four at once, they said that they forgot one form. At fast speeds, they were only able to see one form, usually the top.

Almost all Ss reported pointing to the forms they really saw first and then guessing. Two four-year-olds who reported guessing first may have been doing this at some ISIs. Adults said that they often used partial cues in guessing, especially for certain forms such as the half moon, the stairs, the clover, and the star. Eight-year-olds did not report using partial cues. One adult S reported using partial cues to reduce the stimulus set from which she selected, i.e., if she saw a form with a vertical line, she would choose from the clover, the rectangle, and the boat. If she had two guesses, she would pick two of these. This may have been the optimal strategy for guessing in this task.

CHAPTER IV

DISCUSSION

Age Differences in Processing Speed.

The findings confirm the prediction that preschool children can process single-item arrays as fast as older children and adults but are slower in processing multiple-stimulus arrays. Thus, their scores did not increase at the same rate as the scores of older Ss as array size and ISI were increased. This is the basis for the reliable interactions between age and array size and between age and ISI. These interactions tend to mask the fact, however, that even on multiple-stimulus arrays, four-year-olds could process one item as fast as older Ss, except on condition three. This is clear from the means of Table 1. It is not clear from the third analysis, however, which showed that the R1 of four-year-olds was significantly below the R1 of older Ss in accuracy at ISIs above 30 msec. (see Figure 11). The discrepancy is apparently due to the fact that four-year-olds did not give their surest responses first on four-item arrays for which they had to report all four items. In addition, this analysis includes condition three, in which four-year-olds could not process one item as fast as older Ss.

In drawing the conclusion that four-year-olds could process one item as fast as older Ss from one, two, and four item arrays, under whole report, it should be noted that they had 15 msec. longer to look at the array than older Ss. Stimulus duration and processing time (ISI) are usually considered to be equivalent in the sense that they can can be traded off for one another, except at low values. Haber (1969a) has shown that varying either stimulus duration or ISI makes no difference as long as the total time remains the same, at least for adults. There is no evidence concerning the applicability of this additivity principle to young children. Thus, if arrays are presented for durations which result in clear viewing for all age groups without a mask, it is difficult to know if the additional viewing time needed for young children should be interpreted as additional processing time. Conversely, if the same duration is used for all age groups, and adults show faster processing time than children, it may be that the extra viewing time, which adults do not need, should be subtracted from the difference in processing time. For example, Liss and Haith (1970) presented a single line for 20 msec. duration to five-year-olds and adults, and the adult threshold for recognition of line orientation was 50 msec. less than the children's in processing time. The results obtained by Dick and Dick (1969) imply that 10 msec. is sufficient for clear perception of line orientation in adults. Thus, the 10 msec. additional viewing which adults received should perhaps be considered as additional processing time. Since Liss and Haith (1970) did not conclude from the absolute differences obtained in their study that there were age differences in processing speed, but rather looked at relative differences under forward and backward masking, this is not a criticism of their interpretation. However, it does point to a methodological difficulty in attempting to compare processing time across age groups.

In any case, it can be concluded from the present results that four-year-olds differ very little from older *Ss* in rate of processing one item, no matter how large the array, but are a great deal slower in processing subsequent items. Their processing of the second item *is* affected by array size and was slower for four-item arrays than for two-item arrays. On two-item arrays, they reached an asymptote of about 1.7 items correct at 250 msec. delay of the mask, and this average was not surpassed on trials without the mask. This asymptote corresponds to that found by Haith _et al_. (1970). However, on four-item arrays, they reached a maximum of only 1.2 items at 250 msec., but this increased to about 1.5 items on no masking trials. Thus, for four-item arrays, presentation of the mask itself, even at long ISIs, reduced accuracy somewhat for four-year-olds. It perhaps merely added to the confusion of the large arrays.

The analysis by report position adds further evidence that four-year-olds have more difficulty in processing the second item. Their R1-R2 decrement in accuracy is much greater at all ISIs than that of older _S_s (see Figure 11). This confirms the finding of Haith _et al_. (1970). However, they also found that the R1-R2 decrement for preschoolers was even more severe for four-item arrays than for two-item arrays. However, in this study, the age x array condition x report position interaction was not reliable. Only when the first two responses were combined was there a drop in accuracy for four-year-olds from two-item arrays to four-item arrays.

Eight-year-olds did not differ from adults in processing speed on one and two-item arrays. However, on four-item arrays, they were slightly slower in processing the second item and much slower in processing the third. Their asymptotic performance on four-item arrays was about 2.3 items, both at the longest delay before the mask (250 msec.) and without the mask. Adults reached a maximum of about

2.6 items on the four-item arrays. This asymptote for adults is somewhat lower than that obtained by Haith et al. (1970), which was about three items. The difference may be attributable either to a difference between the subject samples or to the more severe guessing correction adopted in this study.

Thus, processing speed for one form does not appear to change to any significant extent from four to twenty years, even as array size is increased. However, the rate at which a second form is processed increases between four and eight years. In addition, for younger children, this rate is affected by the size of the array, and they have difficulty processing a second item at all when there are more than two items displayed. The rate at which a third form is processed increases between eight and twenty years, and eight-year-olds have difficulty processing a third item from a four-item display.

These findings imply that four-year-olds can always focus on one item no matter how many items there are, at least up to four. They can even take in two forms much of the time if only two forms are shown, although it takes them longer to get the second than the first. However, if more than two forms are shown, their processing capacity decreases, perhaps because it becomes overloaded and they have no efficient processing strategy. This possibility will now be examined.

Age Differences in Processing Strategy

It was predicted that adults would show a parallel dependent processing strategy. This means that processing time for an item was expected to increase as array size increased. Thus, at each ISI interval, mean accuracy would be lower for the larger arrays. This prediction was not confirmed. The means of Table 1 show that adults processed twice as much from two-item arrays at every ISI than from single-item arrays. This indicates perfect parallel *in*dependent processing. However, they were not able to process twice as much from the four-item arrays as from the two-item arrays. Their means on the four-item arrays are only about .3 to .5 higher at each ISI than their means on the two-item arrays.

Eight-year-olds also showed perfect parallel *in*dependent processing as array size was increased from one to two items. However, it was only at low ISIs that they could process even slightly more from four-item arrays than from two-item arrays. At middle ISIs, the means are about equal on two and four-item arrays, and this is indicative of serial processing. Furthermore, it was not until the second item was processed at 80% accuracy on the two-item array that processing of the third item of the four-item array began. This is also indicative of serial processing.

Four-year-olds showed some parallel processing as array size increased from one to two items. However, they did not process twice as much at each ISI from the two-item arrays. Thus, their processing cannot be characterized as perfect parallel independent processing.

It is clear from Table 1 that this is because they could process the first item of two-item arrays twice as fast as the single item on single item arrays, but they could not process both items of two-item arrays equally as fast as the single item arrays.

For all age groups, processing time for one item decreased as array size increased from one to two to four items. This is indicative of a parallel independent strategy. However, only eight-year-olds and adults were able to process two items in parallel, and no S could process three items in parallel. Thus Figure 6 shows that scores on the two and four item arrays were consistently higher than scores on the single item array at all ISIs, but no consistent differences were found between the two and four-item arrays.

When only the first two responses of condition four are included in the analysis, the slight differences found for adults between two and four-item arrays disappear (see Table 2). This may be due to the fact that even adults did not all give their surest responses earliest in the response sequence.

Age Differences in Selective Processing

Four-year-olds and adults took longer to process two specific items out of four than two items when there were only two in the array. In addition, adults took longer to process two specific items out of four than any two items out of four. Eight-year-olds showed similar trends to adults, but the difference between their scores under condition three (selective processing) and their scores under other conditions did not reach significance. The difference between eight-year-olds and adults in this comparison is due to the fact that eight-year-olds were slightly better than adults in the selectivity condition but slightly worse than adults in the four, report four condition. Both older age groups did significantly better than four- year-olds in reporting two items under all three conditions: two-item arrays, two selected items of four-item arrays, and any two items of four-item arrays. However, Figure 8 shows that the groups were closer on the two-item arrays. Age differences on the four-item arrays were not greater under selective processing, as predicted. Four-year-old scores appear from Figure 8 to differ equally from older Ss in conditions three and four. This is surprising, since the means of Table 2 show that four-year-olds had difficulty processing even one item except on no masking trials under condition three. Table 1 indicates that on all other conditions they could process one item as fast as older Ss. The discrepancy again appears to lie in the fact that four-year-olds did not give their surest responses first. Thus, taking only their first two responses under condition four deflates their scores considerably as compared to when all four responses are considered. If the means obtained under selective processing are compared to the means under full report of four items, it is clear that four-year-olds did much worse under selective processing. They also did relatively worse than other age groups under selective processing than under full report.

Thus, for all age groups the presence of extraneous items interfered with processing. Their processing times were faster when the extra items were not there (condition two). The presence of extraneous items was also more interfering than the presence of additional items to be reported. In other words, it took them longer to locate two specific items out of four and process them than to process the two items out of four when these could be any two. These tendencies were not as strong for eight-year-olds, but they showed trends similar to the other age groups.

These results do not support Neisser's sequential model in which a preattentive parallel stage is followed by an attentive serial stage of processing. This model implies that processing of the two extraneous items should be restricted to a preattentive level. Thus, processing time for two selected items out of four should differ from processing time for two-item arrays only by the time required to process the two extraneous items preattentively, i.e. very minimally. Processing time for two selected items out of four should not differ at all from processing time for the first two items out of four, since under both conditions, the other two items should be processed only preattentively, at least at first. However, these results showed that even adults appeared to be unable to restrict processing of extraneous items to a preattentive level. Thus, they took longer to process two selected items out of four than two-item arrays. Of course, part of the difficulty may have been due to the fact that S̲s had to locate specifically the top and bottom items in the four-item arrays. There is evidence (Liss, personal communication) that adults have difficulty processing position information at low ISIs. In this study, adults seemed to need about 30 msec. to see where the items were. After 30 msec., intrusion errors, i.e., incorrect reporting of side items decreased rapidly for adults. Before 30 msec., intrusion errors increased with increasing ISI for adults, indicating perhaps that they could identify the side items before they could tell where they were and screen them out. Intrusion errors for eight-year-olds were slightly more frequent than for adults at 0 msec. and then decreased steadily as ISI increased. Thus, eight-year-olds seemed to see more of the side items at 0 msec.,and they began to screen them out sooner than adults. Four-year-olds continued to make about the same number of intrusion errors as ISI increased, and it was only on trials without the mask that they could screen out the side items. Thus, as in the four, report four condition, the mask seems to have been an added confusion for four-year-olds.

Some of the difference found between condition three and the first two items of condition four might also be explained by a difficulty in locating the top and bottom positions specifically. Presumably, it is easier to process items in any order, since in this case, their position does not have to be processed. Moreover, on four-item arrays, the top item was closer to the side items than to the bottom item. Thus, it might have been easier for Ss to process the top and side items together, under the four, report four condition, than the top and bottom items together, as required under the four, report two condition. However, the percentages of second items which were left or right items only slightly exceeded the percentage which was bottom items under condition four (see Table 14), and many adults, in particular, showed a top-bottom strategy even under condition four.

Age Differences in Masking Effects

Both groups of children obtained higher scores than adults under all conditions when the mask immediately followed the stimulus array (0 msec. ISI). Moreover, four-year-olds did slightly better than eight-year-olds, except under condition four. Eight-vear-olds continued to outperform adults at 15 msec. ISI. Thereafter, the age trend was reversed.

Significant age x ISI interactions were found in all analyses. However, the difference between age groups at 0 msec. was reliable only for R1 in the last analysis. On R1 at 0 msec., both groups of children scored higher than adults, but only the difference between four-year-olds and adults was significant. Eight-year-old scores on R1 were also higher than adult scores at 15 msec, but not significantly. Four-year-olds' and eight-year-olds' scores did not differ significantly at either 0 or 15 msec. ISI. Further evidence for age differences in performance at 0 msec. is that a much smaller percentage of adult errors at this ISI were intrusion errors, as compared to both groups of children.

These findings appear to indicate that adults see less at 0 msec. than children. Not only do they identify fewer items correctly, but also, under condition three, they make relatively fewer intrusion errors as compared to other errors. There are several possible explanations for this age difference. A simple one is that the children were not obeying instructions to fixate the fixation dot as well as adults. This may have been because they were not able to maintain their fixation as well as adults. A slight displacement of fixation might have allowed them to pick up more information from the array than adults. At 0 msec. ISI, a slight displacement would be expected to give them a relatively greater advantage than at longer ISIs. However, one problem with this interpretation is that for one and two-item arrays, the displacement would have to have been directed specifically toward the top or bottom of the array to be an advantage.

Furthermore, for one-item arrays, the position of the form was uncertain. Thus, it would seem that age differences in fixation might be shown best by a tendency in children to get either the top or bottom correct more often on one-item arrays at 0 msec. This tendency is found in only one four-year-old, who had three correct in the top position and only one correct in the bottom at 0 msec., and in one eight-year-old, who had more correct on the bottom. All other Ss in both age groups had about an equal number correct in both positions at 0 msec. This evidence does not appear to support a displacement interpretation. However, more precise measures of fixation are needed, e.g. retinal photography, before it can be dismissed.

Another simple explanation is that the individual random orders for ISI might not have been balanced across Ss in each age group, such that an equal number of Ss in each age group received the 0 msec. block of trials under each condition early and late in the testing sessions. It was expected that practice effects would be minimal, because of the prolonged practice session administered before testing and the initial practice trials given at the beginning of each test session. Nevertheless, four-year-olds appeared to show some effects of practice. The distribution of the 0 msec. interval across four-year-olds was not ideal for condition one. All Ss had had at least three blocks of trials under condition one before the 0 msec. block. All other ISIs were more evenly distributed across trials. However, under all other conditions, the 0 msec. ISI block was given to two Ss in the first block of trials, to two Ss in the middle of testing, and to two Ss within the final three blocks of trials for each condition. Thus, practice effects in conditions two, three, and four should have balanced out somewhat across all four-year-olds. Nevertheless, they still obtained higher scores than adults at 0 msec. ISI under these conditions. The age difference is not attributable to the distribution of the 0 msec. ISI across trials for adult Ss either, under conditions two, three, and four.

A more complex interpretation would view the age differences in masking effects at 0 msec. ISI as differences in the perception of successiveness. When a spatially overlapping mask, of the type used in this study, is presented simultaneously with the target, the overlapping black areas summate, and thus, the target figures show greater contrast. With this type of mask, then, summation effects act to enhance recognition under concurrent presentation of target and mask. It is only when the target and mask are perceived successively that the mask begins to stop processing of the target more centrally. The superior performance of children at 0 msec. delay of the mask, then, may be attributable to the fact that they perceived the target and mask simultaneously at this ISI, whereas adults perceived them successively.

Other evidence that children's perception of target and mask is simultaneous at 0 msec. is that their accuracy under conditions two and three is the same at this ISI. Only at 15 msec. does their accuracy under the four, report two condition become lower than for two-item arrays. Thus, the extraneous items do not appear to interfere with their processing of the selected items until 15 msec. ISI. It is true that, compared to adults, they report more of the extraneous items incorrectly relative to other items not on the card at 0 msec. ISI However, since their accuracy does not differ under conditions two and three, the extraneous items are apparently being processed in a parallel independent fashion with the selected items, rather than interfering, at 0 msec. ISI. Adults, on the other hand, show interference from the extraneous items at 0 msec. ISI, since their accuracy is lower under condition three than under condition two. According to Liss (personal communication), there is no interference from other items until the target and mask are percieved successively.

Finally, the means of Table 1 show a drop in accuracy for four-year-olds from 0 msec. ISI to 15 msec. ISI under conditions one, two, and three. This drop was found for four out of six Ss in all three conditions and could be due to the change from simultaneous perception to successive perception of target and mask. Under condition four, the drop occurred for four Ss between 15 and 30 msec. ISI. It is unclear why the drop should occur later in this condition if a simultaneity versus successiveness interpretation is correct.

Age differences in the perception of successiveness have been pointed out previously by Pollack, Ptashne, and Carter (1968), who found a decreasing threshold for perception of an interval between flashes with increasing age between six and ten years. This decrease with age is attributed to physiological aging of the visual receptor, which results in decreased persistence of the initial stimulus trace. However, the difficulty with Pollack's study is that the younger children's detection criterion probably differed from that used by older Ss. Furthermore, the interpretation of the age difference is probably not correct, since Sheingold's (1971) study, described in part A, indicates little change with age in the rate of decay of the visual trace.

It is not clear, then, if the age differences in performance at 0 msec. ISI can be attributed to age differences in perception of simultaneity versus successiveness of target and mask. The question is an interesting one and merits further investigation.

Age Differences in Form Difficulty

The three age groups showed remarkable similarity in relative difficulty of the twelve forms. When the forms were grouped in terms of the four easiest, the four of medium difficulty, and the four most difficult, eight of the twelve forms belonged to the same category for all age groups. The half moon, the spoon, and the thin rectangle were easiest for all ages, the star and the boat were of medium difficulty, and the arrow, square, and triangle were most difficult. The three easiest forms can perhaps be characterized as the simplest in terms of number of lines. The half moon had two lines, but only one was sufficient to identify it. Similarly, the spoon and the thin rectangle could be identified from detection of a single horizontal or vertical line. Dick and Dick (1969) have shown that less exposure duration is needed to identify line orientation than forms, and this finding has been replicated for nineyear-olds (Dick, personal communication). The circle was also very easy for children, but this may have been because it was a highly preferred response. For adults, the stairs were very easy, and their reports indicated that this was because it was identifiable from partial cues. Apparently, this is also why the half moon and circle were not often confused, since Ss were able to pick out the points of the half moon. However, Ss also reported that they could identify the star from its points, and yet this was not found to be a very easy form.

Forms of medium difficulty were generally those that were most complex: the star and the boat for all groups, the clover for adults, and the stairs for children. Apparently, their greater complexity made them more distinctive than the more difficult forms but, except in the cases where they could be identified from partial cues, more difficult than the very simple forms. The plus sign was of medium difficulty for eight-year-olds also, perhaps because it was one of their more preferred forms. For other Ss, it was more difficult. The most difficult forms, the arrow, square, and the triangle, along with the plus sign for most Ss, might be characterized as simple enough to be very confusable with other forms, i.e., not very distinctive, but not simple enough to be identified from a single line. In addition, part of all these forms was included in the mask, and, therefore, it might be expected that they would be better masked than the spoon and the star, for example, which were not part of the mask. However, the circle and rectangle also formed part of the mask, and they were among the easiest forms. Furthermore, the clover, which also was not part of the mask, was a very difficult form, at least for children. This may again be due to response bias, since it was one of the least preferred forms for children.

It appears that form difficulty is not related to nameability or even familiarity. All the children were familiar with the square and the triangle and could name them. Yet, they were still very difficult forms to process. The "boat" and the "spoon" were more abstract (these are arbitrary names) and less familiar, and the children had difficulty naming them. Yet, the spoon was one of the easiest forms, and the boat was of medium difficulty.

Form difficulty was also not related to the position of forms on the response card. The forms in the three categories of difficulty for each age group were well distributed on the response card. There was, however, some relation between response bias and position of forms on the response card for four-year-olds. Five of the six forms on the bottom half of the card were among their less preferred forms. This relation was not found for the older age groups.

In general, the results for form difficulty reveal a methodological problem involved in attempting to evaluate difficulty or confusability independently of preference. The most frequently given confusion responses tended also to be the most preferred responses. In addition, there is some correspondence between the more preferred forms and the easiest forms and between the less preferred forms and the most difficult forms, especially for children. There are exceptions, however. All groups tended to avoid the half moon or the spoon, which were easy forms for all Ss. This may have been because they gave them so often as correct responses that they tended to give them less as incorrect responses. Thus, even the youngest children may have had some idea that all forms should be pointed to an equal number of times.

In general, then, form difficulty and confusability appear to be somewhat confounded with response bias. It is possible that Ss made fewer errors on some forms simply because they pointed to them more frequently and, thus, had to be correct more often. Conversely, it is also possible that S pointed more frequently to those forms which they found to be easiest. Nevertheless, the comparisons between age groups are still valid. Despite the general correspondence between form difficulty and form preference within each age group, there was more correspondence between age groups in the relative difficulty of forms than in form preference. This was also found by Haith et al. (1970). However, in their study, adults showed stronger biases than children, while the reverse was true in this study. The relative difficulty of forms used in both studies also differs somewhat. In the study by Haith et al (1970) the line was relatively more difficult and the square and arrow relatively easier for both children and adults. Also, the circle was easy for adults and difficult for children. The opposite results were found in this study. The star and triangle were of equal relative difficulty in both studies.

The conclusion drawn in both studies, that the relative difficulty of forms changes little with age from four to twenty years, is supported by a recent study by Owen (1971). By means of a multivariate analysis, Owen determined that a five-year-old S made use of the same form characteristics of random shapes as adults in a visual search task. However, adults took half the time to find the target, possibly because they could process these characteristics in parallel or in higher level combinations, e.g., the relative proportion of width to height instead of width and height separately.

Theoretical Implications of Findings

I. Implications for Models of Information Processing

The findings of this study showed that adults processed at least two items in a parallel independent fashion. However, when they had to restrict processing to two specific items out of four, they were no longer able to use a parallel independent strategy. These results, as stated earlier, do not support Neisser's two-stage model, in which preattentive spatially parallel processing is followed by serial attentive processing. _S_s in this study were apparently unable to restrict their processing of extraneous items to a preattentive level. Nor did they encode the features of each item one at a time. Apparently, they took in at least two forms in one glance, and they performed some feature analysis before spatial analysis. At least, the intrusion data for adults seem to show that forms could be seen enough to identify them before it was possible to tell exactly which position they occupied.

This implication appears to be in disagreement with the finding of Dick and Dick (1969) that the threshold for spatial location is lower than the threshold for form identification. Furthermore, Finkel, Sheingold, and Haith (1969) found that _S_s were better at processing spatial configuration than details of a pattern. Since _S_s in the present study did not have to report forms in their correct position, they may have adopted a set for processing item information before spatial information. In addition, however, it seems that there are really two types of spatial information. The first is simply spatial configuration, i.e. the black and white parts of the pattern, or filled versus unfilled spaces. This type of information appears to be processed at a very low level. The second type is the location of a particular form in its space. This information may be processed as an additional feature of the form, and thus it may be processed on a higher level than the first type of spatial information. It is possible that Neisser's preattentive mechanisms handle only the first type of spatial information. In that case, the fact that S̲s could not restrict their processing of extraneous items to a preattentive level may not contradict his model, since the task involves processing of the second type of spatial information. The same point, essentially, was made in Part C of this chapter.

Liss (personal communication) found that adults take longer to process two specific items out of four than two items alone but that they do not take longer under selective processing than when they have to report all four items. The findings of this study agree with the first result but not the second. However, the partial agreement is interesting, since the stimuli and the distances between them differ in the two studies. Liss's items were vertical or horizontal dot pairs, and the items were not all included in the fovea but were about 3^{o} apart.

Thus, even at this distance, the presence of extraneous items seems to interfere with the processing of two selected items, as compared to the processing of two items in the absence of extraneous items. However, at this distance, interference on report of two items is not greater from extraneous items than from two additional items to be reported. Thus, interference in a selective processing task may be greater the closer items are to each other, as Liss and Reeves(1971) have found in a dot location task. At a distance of 3°, Liss (personal communication) also found that there was no interference at low ISIs, whereas in the present study, for adults, accuracy was lower under condition three at all ISIs.

The major discrepancy between the results of this study and other studies, however, is the finding that adults use a parallel independent processing strategy. This result does not agree with the findings of Liss (pers. comm.), Sperling (1967), or Haber (1969a). These studies have all shown parallel dependent processing. Haber did find that adults could process up to four items as fast as one with a great deal of practice. However, the Ss were considerably more practiced than the subjects in this study.

There are several possible explanations for the discrepancy in results. Two procedural differences between this study and the others were that 1) Ss did not have to report items by position and 2) the forms were arranged circularly with all information included within 1.5° of the foveal center. It is possible that more item information can be processed in parallel if location information does not have to be processed. However, this does not explain why items are processed twice as fast on two-item arrays as on single-item arrays. Furthermore the advantage of reporting items in any order over having to report them by position should disappear as ISI is increased and processing of location information apparently becomes easier. However, in this study, processing was found to be parallel independent at all ISIs, as array size was increased from one to two items.

The second procedural difference was intended to control for variations in retinal sensitivity and in masking effects by retinal location. Thus, it is possible that two forms could be processed as fast as one because they were both in the fovea and stimulated the receptor equally. However,in the horizontal arrangements used by Sperling and Haber, at least two items were as close together in the fovea as the stimuli in this study, but even those were not processed according to a parallel independent strategy. Furthermore, Liss and Reeves (1971) have found that the closer items are in the array, the more interfering they are.

Another possible explanation for the discrepancy in results is that the mask used in this study did not stop processing of input. This means either that Ss could read the target somewhat through the mask or that the effects of the mask were limited to partial summation effects. The fact that the two older age groups showed maximum masking at 0 msec. ISI seems to rule out the first possibility. The second possibility is harder to disprove. However, the similarity between the type of mask used and those which have been found to stop processing (e.g., Liss, 1968) makes this possility unlikely.

The most likely explanation of the discrepancy in findings is that this is the only study which used forms as stimuli. Moreover, the forms were piloted so that those chosen would be maximally distinctive and minimally confusable for all age groups. Sperling (1967) and Haber (1969a) both used letters, while Liss (pers. comm.) used pairs of dots. Letters may be simpler than forms, but for that reason they may be less distinctive, as was speculated about the most difficult forms in this study. Pairs of dots varying only in orientation would be even more similar. If interference increases with increasing similarity of items in processing, as it seems to do in memory, then increasing the number of similar items may result in greater interference and increased processing time. In other words, it may be more difficult to analyze items independently in parallel if they are very similar. The more items there are which are similar, the greater the interference. Thus, processing time for each item would increase with an increase in the number of other similar items. If items are very dissimilar and distinctive, then it may be easier to process them simultaneously and independently.

Shapes may also be more resistant to interference than letters because they are more difficult to encode than letters (Mackworth, 1964). Mackworth found that shapes were more difficult to memorize than letters but that recall of shapes was less affected by interfering _dissimilar_ materials, such as digits and colors, than recall of letters. Mackworth suggests that more difficult materials require greater attention during encoding and that the stability of an item might be a direct function of the amount of attention paid to it during encoding. Presumably, if her explanation is correct, more difficult materials are more resistant to interference from similar as well as dissimilar materials. However, this question needs to be investigated.

II. Implications for Developmental Theories

The results of this study indicate that the difference in short-term memory capacity found by Haith _et al_. (1970) between preschool children and adults can be largely attributed to age differences in both processing speed and strategy. The fact that a single form is processed equally fast at all ages, however, seems to stress the importance of changes in strategy rather than speed. The question, then, is what implications do these findings have for quantitative versus qualitative views of perceptual development? Does a change in strategy or the adoption of a strategy during development represent a qualitative change?

Piaget apparently would attribute all age differences in this study to quantitative change. For him, changes in primary field effects under brief tachistoscopic exposures involve only quantitative increases in the number and distribution of encounters. As discussed in the Introduction, qualitative change requires use of the mechanism of decentration, which cannot occur without eye movements. Decentration involves the coordination of centrations and, thus, is not relevant to a single centration.

Gibson also implies that a strategy change is not a qualitative change. "A theory of parallel processing does not, so far as I can see, suggest that there are any qualitative changes, developmentally, in perceptual activity" (Gibson, 1966, p.24). She suggests that developmental differences in processing might be due to two changes. First, the features of forms might become better differentiated and more economical. Second, the strategy "can shift from a random, poorly ordered, perhaps repetitious one to one which has optimal utility for the task" (p. 24). With respect to the first change, the similar difficulty of forms for all age groups seems to indicate that _S_s of all age groups were utilizing the same features in processing. Furthermore, the fact that the first item of all arrays was processed equally fast by all age groups seems to show that they were all processing these features in a similar way. It seems that if adults were processing them more economically, or on a higher level, they would have processed even the first item faster than children. The change with age appears not to lie in the processing of features of forms but in the processing of number of forms. Thus, it is rather the second change described by Gibson which is involved. Young children seem unable to organize their processing so that they can either focus on one item after another efficiently, in serial fashion, or take in two items in parallel. Presumably, what may happen is that they focus on one item in a display, and this item then interferes with their processing of subsequent items, perhaps because they repeat their processing of the first item. It is then possible that the same lack of strategy, including random and repetitious processing, which is found in tasks involving eye movements (Vurpillot, 1968),is found in tachistoscope tasks which do not involve eye movements.

The question of whether a change in strategy is a qualitative or quantitative change seems to be a question of the degree to which perceptual strategies involve cognitive structures, at least for Piaget. For Gibson, perception and cognition are not considered to be separate systems. For Piaget, they are separate systems, but they interact in the sense that perception is increasingly "corrected" by cognitive structures as age increases. An information processing approach also considers perception and cognition to be interacting. However, the point is not to determine how cognitive structures correct perception increasingly with development, but to analyze all of the components which could be involved in a developmental change in operations. These could include changes in sensitivity of the visual receptor, changes in encoding, changes in input or retrieval processes, and so forth. A single change in operations can involve changes in many processes along the continuum from sensation to perception to cognition. Thus, focussing upon changes in feature differentiation or in decentration alone does not appear to be sufficient to explain what is changing with age in the processing of visual information. The question, then, of whether a change in strategy is a qualitative change because it involves changes in the cognitive structure seems to be an oversimplified question.

In fact, the findings of this study could be attributed to at least three different components which change with age. Young children might not be able to process in parallel because they do not have an efficient "scanning" strategy, as suggested. Or they may also have less efficient encoding or retrieval systems. Furthermore, the fact that they are slower in processing the second item might be because their rate of encoding is simply slower. Or it might be because they have to encode it to a greater degree than adults so that it can survive greater interference from other items in storage or retrieval.

Thus, it is not clear from this study alone that the change in processing strategy with age can be viewed independently of possible changes in encoding and retrieval strategies. Another study is then required which would eliminate the memory component and see if similar findings are obtained. Possibly, a same-different task, similar to that used by Donderi and Zelnicker (see Part C of Introduction) would be useful in determining if the change in strategy can be totally attributed to changes in input processing.

TABLE 1

Mean Forms Correct under All Stimulus Array Conditions (Corrected for Chance)

		Stimulus Condition			
Group	ISI	One item, report one	Two items, report two	Four items, report four	Four items, report two
Four-year-olds	0	.30	.55	.57	.56
	15	.27	.41	.71	.16
	30	.49	.82	.56	.34
	60	.73	1.07	.72	.50
	90	.73	.96	.95	.36
	150	.85	1.43	1.25	.52
	250	96	1.66	1.10	.57
	No Mask	--	1.66	1.45	1.22
Eight-year-olds	0	.20	.38	.65	.37
	15	.44	.72	.95	.54
	30	.49	.99	1.22	.84
	60	.85	1.40	1.41	1.01
	90	.97	1.81	1.80	1.25
	150	.97	1.87	2.20	1.59
	250	1.00	1.81	2.33	1.72
	No Mask		1.91	2.29	1.88
Adults	0	.08	.34	.45	.13
	15	.32	.58	1.11	.26
	30	.56	.94	1.41	.38
	60	.70	1.64	1.92	1.01
	90	.91	1.72	2.23	1.30
	150	1.00	1.88	2.43	1.53
	250	1.00	2.00	2.55	1.87
	No Mask	--	1.97	2.55	1.90

TABLE 2

Mean Forms Correct for Two Items Only, Under Conditions
II, III, and IV (Corrected for Chance)

	Four-year-olds			Eight-year-olds			Adults		
ISI	Cond.II 2 Items	Cond.III 4 Items report 2	Cond.IV 4 Items report 4 (First 2 Items Only)	Cond.II 2 Items	Cond.III 4 Items report 2	Cond.IV 4 Items report 4 (First 2 Items Only)	Cond.II 2 Items	Cond.III 4 Items report 2	Cond.IV 4 Items report 4 (First 2 Items Only)
0	.55	.56	.30	.38	.37	.52	.34	.13	.20
15	.41	.16	.60	.72	.54	.80	.58	.26	.87
30	.82	.34	.52	.99	.84	1.07	.94	.38	.94
60	1.07	.50	.42	1.40	1.01	1.18	1.64	1.01	1.57
90	.96	.36	.81	1.81	1.25	1.56	1.72	1.30	1.76
150	1.43	.52	1.03	1.87	1.59	1.81	1.88	1.53	1.80
250	1.66	.57	1.02	1.81	1.72	1.69	2.00	1.87	1.84
No Mask	1.66	1.22	1.31	1.91	1.88	1.77	1.97	1.90	1.84

Note.--Each mean is based on 36 trials: 6 trials per S in each age group.

TABLE 3

Summary of Analysis of Variance Under Whole Report Conditions: I, II, and IV

Source of variation	SS	df	MS	F
Between subjects	19.680	17		
A (Age)	12.426	2	6.213	13.19***
Subj. w. groups	7.068	15	.471	
Within subjects	158.458	360		
B (Array Size)	33.714	2	16.857	198.32***
AB	8.362	4	2.090	24.58***
B X subj. w. groups	2.547	30	.085	
C (ISI)	71.188	6	11.865	115.19***
AC	6.003	12	.500	4.85***
C X subj. w. groups	9.302	90	.103	
BC	4.903	12	.408	3.88***
ABC	3.452	24	.144	1.37
BC X subj. w. groups	18.987	180	.105	

*** $p < .001$

TABLE 4

Summary of Analysis of Variance on Report of Two Items under Conditions II, III, and IV

Source of Variation	SS	df	MS	F
Between subjects	29.662	17		
A (Age)	22.271	2	11.135	22.59***
Subj. w. groups	7.391	15	.493	
Within subjects	155.107	414		
B (Array condition)	9.595	2	4.797	47.03***
AB	1.883	4	.471	4.62**
B x subj. w. groups	3.065	30	.102	
C (ISI)	94.372	7	13.482	164.41***
AC	11.087	14	.792	9.66***
C x subj. w. groups	8.629	105	.082	
BC	3.786	14	.270	2.90***
ABC	3.153	28	.113	1.22
BC x subj. w. groups	19.537	210	.093	

** $p < .01$
*** $p < .001$

TABLE 5

Summary of Analysis of Variance on First versus Second Response under Conditions II, III, and IV

Source of variation	SS	df	MS	F
Between subjects	14.901	17		
A (groups)	11.175	2	5.588	22.50***
Subj. w. groups	3.726	15	.248	
Within subjects	111.467	846		
B (report position	13.862	1	13.862	571.41***
AB	1.417	2	.709	29.21***
B X subj. w. groups	.364	15	.024	
C (array condition)	4.804	2	2.402	46.76***
AC	.942	4	.236	4.61**
C X Subj. w. groups	1.542	30	.051	
BC	.104	2	.052	1.81
ABC	.213	4	.053	1.85
BC X subj. w. groups	.861	30	.029	
D (ISI)	47.052	7	6.722	164.18***
AD	5.536	14	.395	9.66***
D X subj. w..groups	4.300	105	.041	
BD	1.190	7	.170	4.22***
ABD	1.223	14	.087	2.17*
BD X subj. w. groups	4.229	105	.040	
CD	1.934	14	.138	2.94***
ACD	1.558	28	.056	1.18
CD X subj. w. groups	9.854	210	.047	
BCD	1.707	14	.122	3.42***
ABCD	1.288	28	.046	1.29
BCD X subj. w. groups	7.486	210	.036	

*$p < .05$

**$p < .01$

***$p < .001$

TABLE 6

Form Difficulty

Rank Order of Forms According to Percentage of Trials on which Each Stimulus Form was Missed, by Age Group

Four-year-olds	Eight-year-olds	Adults
Half Moon -- 34%	Half Moon -- 19%	Half Moon -- 21%
Circle -- 39	Spoon -- 22	Rectangle -- 29
Spoon -- 41	Rectangle -- 31	Stairs -- 29
Rectangle -- 46	Circle -- 34	Spoon -- 31
Star -- 49	Stairs -- 35	Boat -- 35
Stairs -- 57	Plus -- 40	Circle -- 38
Boat -- 57	Star -- 43	Clover -- 43
Plus -- 60	Boat -- 45	Star -- 43
Arrow -- 64	Square -- 47	Arrow -- 44
Square -- 65	Clover -- 47	Plus -- 44
Clover -- 67	Triangle -- 49	Square -- 49
Triangle -- 72	Arrow -- 51	Triangle -- 50

TABLE 7

Percentage of Errors Made at Each ISI for Each Stimulus Form by Adults (All Stimulus Conditions Combined)

	ISI							
	0	15	30	60	90	150	250	No Mask
Half Moon	63%	21%	26%	7%	4%	13%	14%	17%
Rectangle	69	50	44	31	16	7	0	12
Stairs	70	54	27	30	18	14	4	12
Spoon	70	76	46	11	10	15	12	8
Boat	65	58	44	31	28	28	11	17
Circle	64	56	62	39	17	21	24	21
Clover	78	77	61	44	26	12	15	25
Star	70	43	61	52	52	23	18	17
Arrow	85	84	59	48	26	32	11	8
Plus	71	74	70	39	37	18	18	25
Square	89	86	63	43	38	35	15	13
Triangle	85	82	61	31	41	33	33	29

TABLE 8

Percentage of Errors Made at Each ISI for Each Stimulus Form by Eight-year-olds (All Stimulus Conditions Combined)

	ISI							
	0	15	30	60	90	150	250	No Mask
Half Moon	37%	21%	22%	21%	11%	8%	7%	25%
Spoon	65	62	8	11	7	7	8	8
Rectangle	73	67	32	21	22	4	15	12
Circle	70	62	61	22	18	18	7	8
Stairs	69	44	31	37	32	28	19	17
Plus	61	48	66	60	14	39	14	17
Star	61	64	54	52	35	23	25	29
Boat	69	46	60	52	41	42	27	25
Square	78	78	76	44	41	21	18	17
Clover	75	72	57	59	38	31	21	17
Triangle	59	82	69	48	56	23	26	25
Arrow	89	60	56	60	52	25	37	33

TABLE 9

Percentage of Errors Made at Each ISI for Each Stimulus Form by Four-year-olds (All Stimulus Conditions Combined)

	ISI							
	0	15	30	60	90	150	250	No Mask
Half Moon	46%	38%	48%	24%	37%	32%	18%	29%
Circle	55	75	42	36	15	35	34	12
Spoon	68	54	44	41	33	32	34	21
Rectangle	60	62	69	39	39	48	33	17
Star	41	48	48	54	50	52	62	33
Stairs	68	78	56	61	73	32	47	38
Boat	68	83	69	43	61	44	50	42
Plus	54	79	57	70	61	48	52	58
Arrow	72	76	78	58	85	50	41	50
Square	79	77	86	62	65	44	50	50
Clover	76	67	66	85	71	52	62	58
Triangle	75	89	82	92	69	64	46	58

TABLE 10

Confusion Matrix for Adults

	Stimulus												
Response	Square	Triangle	Circle	Plus	Arrow	Rectangle	Half Moon	Star	Stairs	Boat	Spoon	Clover	Total
Square	--	5	4	2	1	4	0	4	2	1	2	7	32
Triangle	6	--	3	3	0	2	2	4	0	2	2	1	25
Circle	7	3	--	2	3	1	0	7	3	1	1	1	29
Plus	5	6	4	--	5	2	3	7	0	5	4	3	44
Arrow	3	2	4	3	--	2	2	1	1	4	3	5	30
Rectangle	4	2	3	3	1	--	0	1	2	4	2	8	30
Half Moon	2	0	0	0	1	1	--	1	0	1	4	0	10
Star	4	2	2	4	3	1	0	--	2	0	2	2	22
Stairs	2	5	1	3	5	1	2	4	--	1	2	4	30
Boat	6	7	0	4	2	0	0	5	3	--	1	3	31
Spoon	1	1	0	0	3	2	1	1	1	0	--	3	13
Clover	3	0	2	4	3	2	0	3	2	1	2	--	22
Total	43	33	23	28	27	18	10	38	16	20	25	37	

Note--Each entry is the number of times that each form, given as an incorrect response, could be scored as a confusion with a stimulus form, totalled across all trials and Ss of this age group.

TABLE 11

Confusion Matrix for Eight-year-olds

Stimulus

Response	Square	Triangle	Circle	Plus	Arrow	Rectangle	Half Moon	Star	Stairs	Boat	Spoon	Clover	Total
Square	--	2	4	3	0	0	1	2	2	3	1	2	20
Triangle	1	--	3	3	2	1	1	0	4	2	0	2	19
Circle	6	5	--	1	2	2	1	8	1	2	0	5	33
Plus	1	7	4	--	4	4	0	9	2	5	0	4	40
Arrow	2	2	3	5	--	1	2	0	2	1	0	2	20
Rectangle	6	7	3	4	9	--	1	2	3	4	3	10	52
Half Moon	4	1	1	4	2	3	--	1	3	4	1	3	27
Star	6	4	2	1	3	4	0	--	2	3	1	1	27
Stairs	7	2	1	4	2	2	0	1	--	4	2	2	27
Boat	4	3	2	3	2	2	2	1	0	--	4	0	23
Spoon	1	1	2	2	7	1	1	1	0	1	--	3	20
Clover	1	3	3	1	2	0	1	2	1	2	1	--	17
Total	39	37	28	31	35	20	9	27	21	31	13	34	

Note--Each entry is the number of times that each form, given as an incorrect response, could be scored as a confusion with a stimulus form, totalled across all trials and Ss of this age group.

TABLE 12

Confusion Matrix for Four-year-olds

<u>Stimulus</u>

Response	Square	Triangle	Circle	Plus	Arrow	Rectangle	Half Moon	Star	Stairs	Boat	Spoon	Clover	**Total**
Square	--	4	3	6	2	3	1	3	4	3	1	3	33
Triangle	3	--	0	1	2	3	3	5	3	3	2	2	27
Circle	12	8	--	5	4	8	3	4	4	4	2	11	65
Plus	2	3	2	--	2	2	1	2	2	7	0	3	26
Arrow	0	5	0	2	—	3	1	2	2	3	1	2	21
Rectangle	9	7	5	6	6	--	2	3	3	3	3	8	55
Half Moon	3	2	4	5	1	1	--	0	3	1	0	4	24
Star	4	4	8	3	3	0	0	--	4	2	5	3	36
Stairs	5	3	0	1	3	2	1	3	--	1	0	2	21
Boat	5	3	4	4		4	1	1	3	--	4	5	36
Spoon	3	2	2	3	7	3	1	4	3	3	--	4	35
Clover	0	2	2	1	5	1	0	0	0	4	0	--	15
Total	46	43	30	37	37	30	14	27	31	34	18	46	

Note--Each entry is the number of times that each form, given as an incorrect response, could be scored as a confusion with a stimulus form, totalled across all trials and <u>S</u>s of this age group.

TABLE 13

Response Bias

Rank Order of Forms According to the Relative Frequency with Which Each Form Was Given Incorrectly

Four-year-olds		Eight-year-olds		Adults	
Circle	-- 15%	Rectangle	-- 12%	Plus	-- 11%
Rectangle	-- 11	Circle	-- 11	Stairs	-- 10
Star	-- 10	Plus	-- 9	Boat	-- 10
Boat	-- 9	Triangle	-- 9	Square	-- 9
Spoon	-- 8	Star	-- 8	Rectangle	-- 9
Square	-- 8	Half Moon	-- 8	Circle	-- 8
Plus	-- 7	Stairs	-- 8	Triangle	-- 8
Triangle	-- 7	Square	-- 7	Star	-- 8
Half Moon	-- 7	Boat	-- 7	Arrow	-- 8
Stairs	-- 7	Clover	-- 7	Clover	-- 8
Arrow	-- 7	Arrow	-- 6	Spoon	-- 5
Clover	-- 4	Spoon	-- 6	Half Moon	-- 4

TABLE 14

Position Report Strategy

Relative Frequency with Which Each Position of the Stimulus Array Was Reported in Each Position of the Report Sequence, by Array Condition and Age Group
(Relative Frequencies for Correct Responses Only Are Given in Parentheses)

Condition II: Two Items, Report Two

Four-year-olds			Eight-year-olds			Adults		
Stimulus Position	Report Position		Stimulus Position	Report Position		Stimulus Position	Report Position	
	First	Second		First	Second		First	Second
Top	54% (53%)	46% (50%)	Top	76% (76%)	24% (20%)	Top	82% (83%)	18% (17%)
Bottom	46% (47%)	54% (50%)	Bottom	24% (24%)	76% (80%)	Bottom	18% (17%)	82% (83%)

Condition III: Four Items, Report Two

Four-year-olds			Eight-year-olds			Adults		
Stimulus Position	Report Position		Stimulus Position	Report Position		Stimulus Position	Report Position	
	First	Second		First	Second		First	Second
Top	54% (58%)	46% (52%)	Top	71% (72%)	29% (28%)	Top	77% (78%)	25% (20%)
Bottom	46% (42%)	54% (48%)	Bottom	29% (28%)	71% (72%)	Bottom	23% (22%)	75% (80%)

(continued)

TABLE 14 (cont.)

Condition IV Four Items, Report Four

Stimulus Position	First	Second	Third	Fourth
		Report Position		
		Four-year-olds		
Top	38% (39%)	18% (18%)	24% (24%)	20% (24%)
Bottom	22% (22%)	27% (27%)	21% (19%)	27% (25%)
Left	12% (12%)	28% (28%)	30% (31%)	23% (21%)
Right	27% (27%)	26% (26%)	25% (26%)	30% (29%)
		Eight-year-olds		
Top	54% (54%)	21% (21%)	10% (12%)	16% (22%)
Bottom	16% (15%)	24% (23%)	31% (30%)	27% (25%)
Left	17% (17%)	28% (28%)	31% (29%)	26% (31%)
Right	14% (14%)	27% (28%)	27% (29%)	30% (22%)
		Adults		
Top	38% (37%)	22% (22%)	27% (28%)	15% (15%)
Bottom	14% (14%)	21% (19%)	25% (22%)	34% (23%)
Left	24% (24%)	26% (27%)	23% (22%)	26% (26%)
Right	24% (24%)	30% (31%)	26% (27%)	24% (35%)

TABLE 15

Total Number of Intrusion and Non-intrusion Errors at Each ISI under Condition Three (Four Items, Report Two) for Each Age Group (Percentage Error Given in Parentheses)

	Four-year-olds			Eight-year-olds			Adults		
ISI	Right Intrusions	Left Intrusions	Other Errors	Right Intrusions	Left Intrusions	Other Errors	Right Intrusions	Left Intrusions	Other Errors
0	4 (9%)	11 (25%)	29 (66%)	12 (24%)	7 (14%)	32 (63%)	11 (18%)	4 (7%)	45 (75%)
15	8 (14%)	7 (12%)	43 (74%)	10 (22%)	5 (11%)	31 (67%)	11 (20%)	7 (13%)	37 (67%)
30	7 (13%)	11 (21%)	35 (66%)	7 (19%)	6 (17%)	23 (64%)	11 (22%)	11 (22%)	28 (56%)
60	7 (15%)	3 (6%)	38 (79%)	3 (9%)	7 (21%)	23 (69%)	9 (28%)	4 (12%)	19 (59%)
90	11 (22%)	2 (4%)	38 (74%)	5 (20%)	7 (28%)	13 (52%)	8 (36%)	3 (14%)	11 (50%)
150	8 (17%)	7 (15%)	31 (67%)	2 (15%)	2 (15%)	9 (69%)	5 (33%)	3 (20%)	7 (47%)
250	9 (20%)	9 (20%)	27 (60%)	2 (22%)	0 (0)	7 (78%)	2 (50%)	0 (0)	2 (50%)
No Mask	3 (12%)	0 (0)	22 (88%)	0 (0)	0 (0)	4(100%)	0 (0)	1 (33%)	2 (67%)
Total	57 (15%)	50 (14%)	263 (71%)	41 (19%)	34 (16%)	142 (65%)	57 (24%)	33 (14%)	151 (63%)

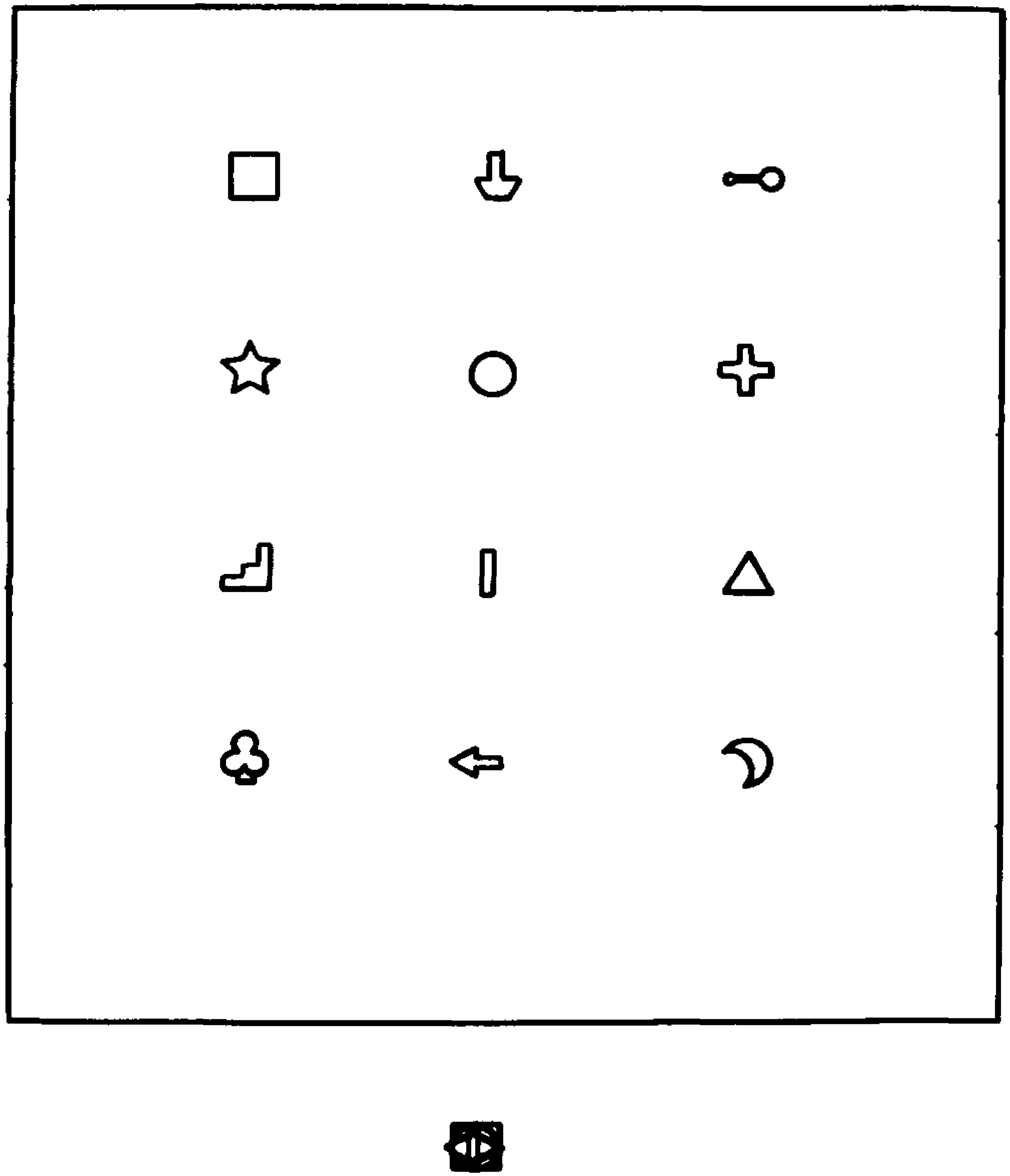


Figure 1. Response Card showing twelve forms used in their actual size, with masking stimulus below.

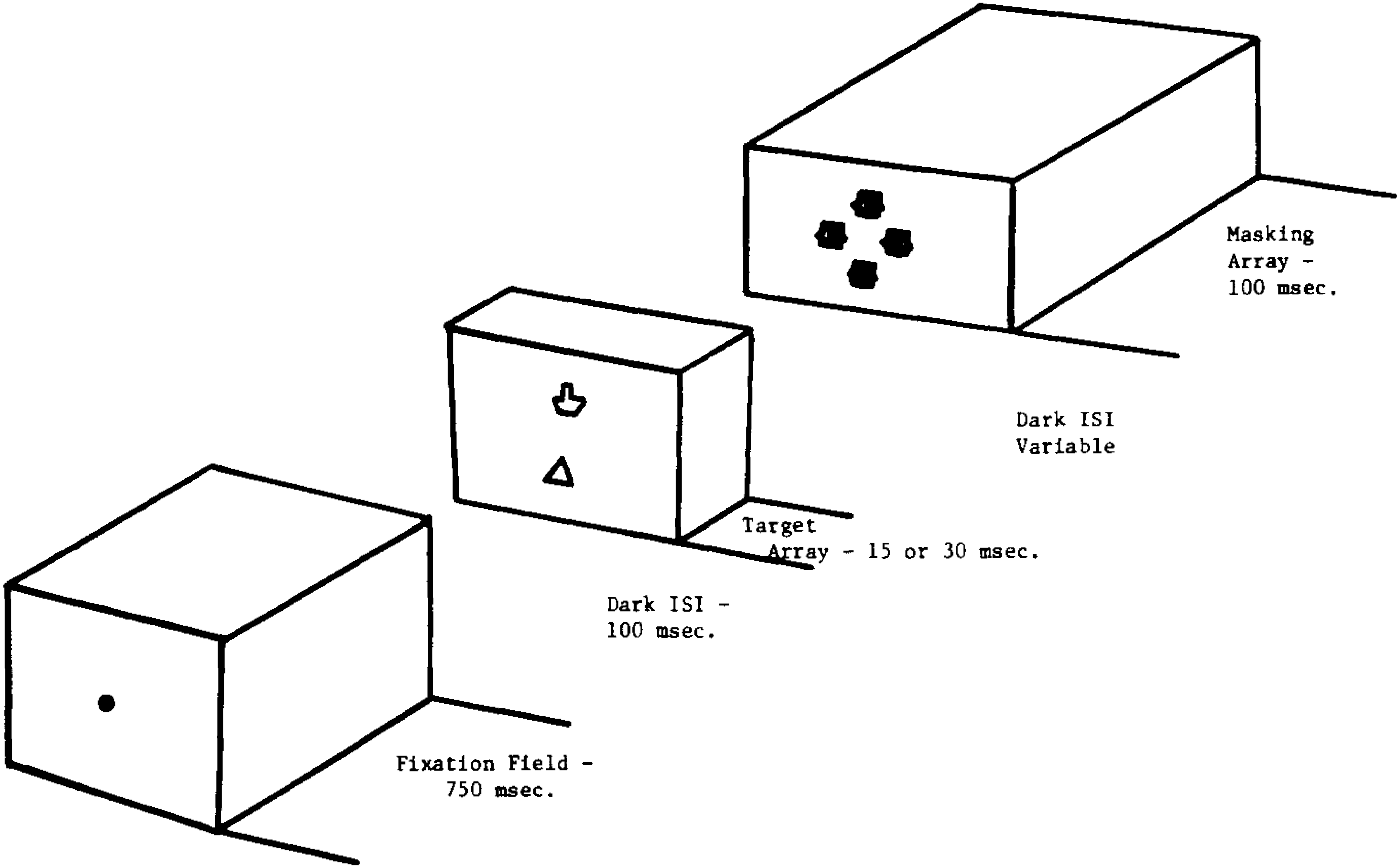


Figure 2. Diagram of a Trial Sequence (After Averbach and Coriell in Averbach and Sperling, 1961).

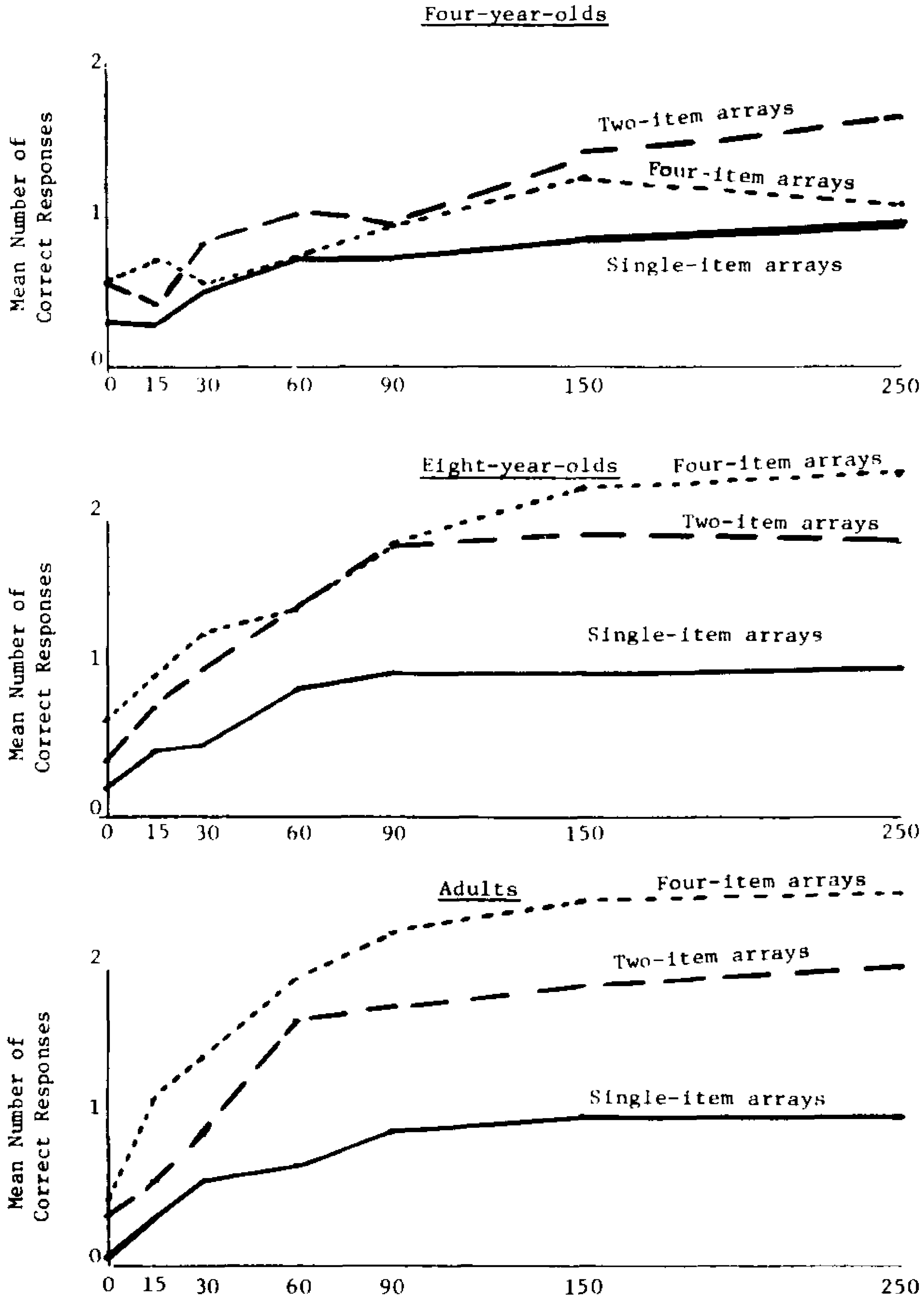


Figure 3. Means at Each ISI for Each Array Size, by Age Group

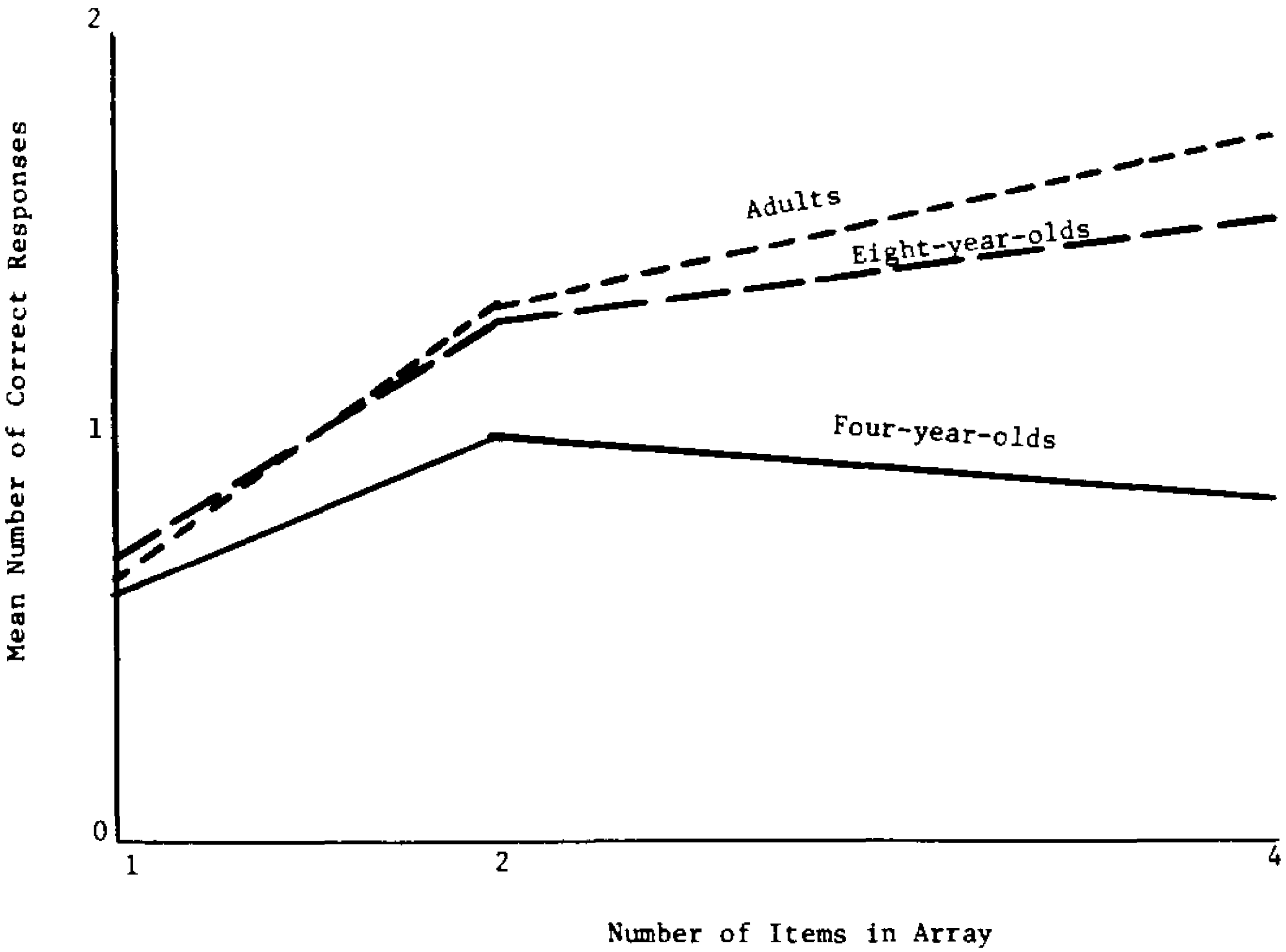


Figure 4. Age x Array Size Interaction, ANOVA 1

Figure 5. Age x ISI Interaction, ANOVA 1

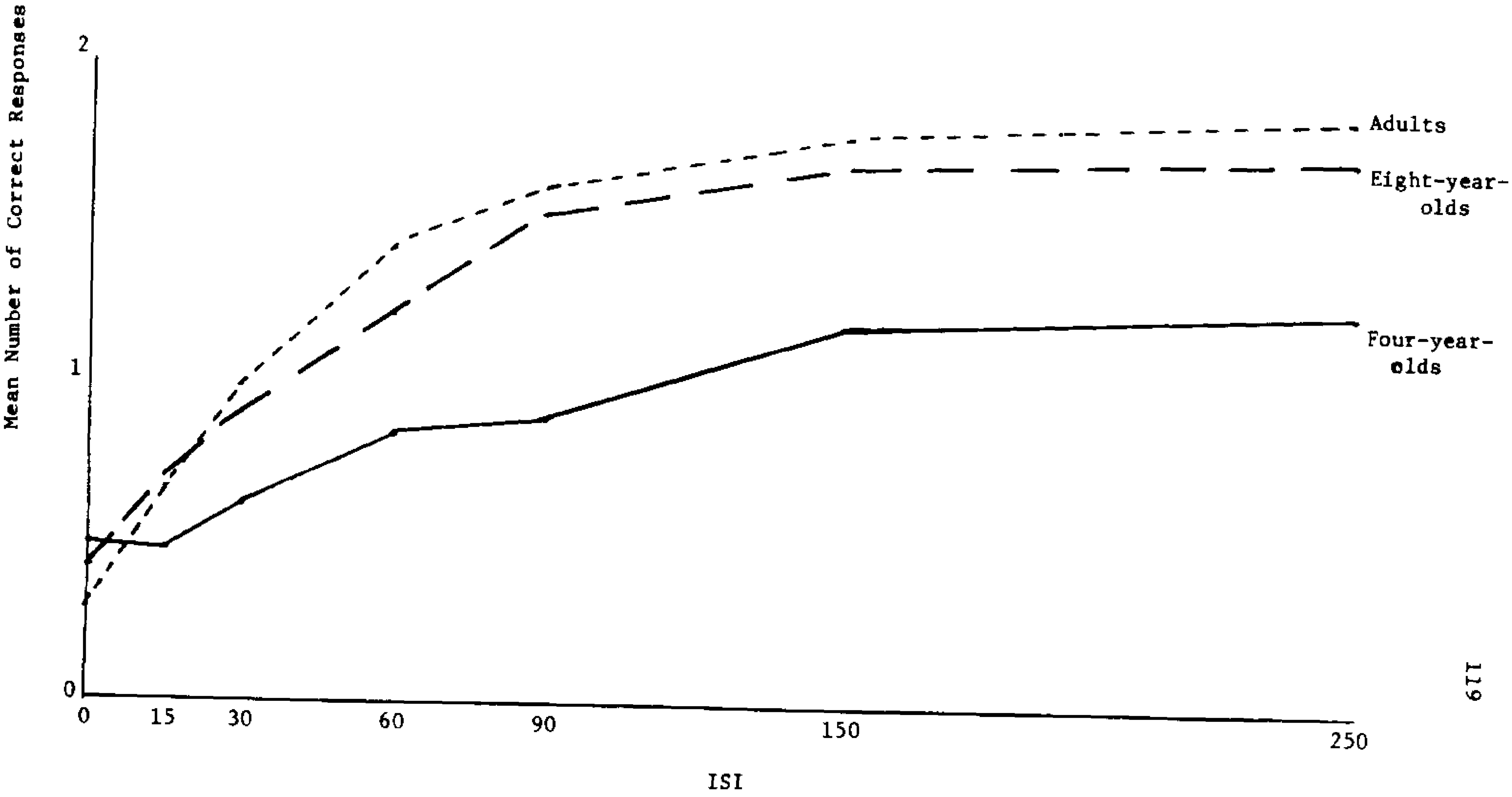
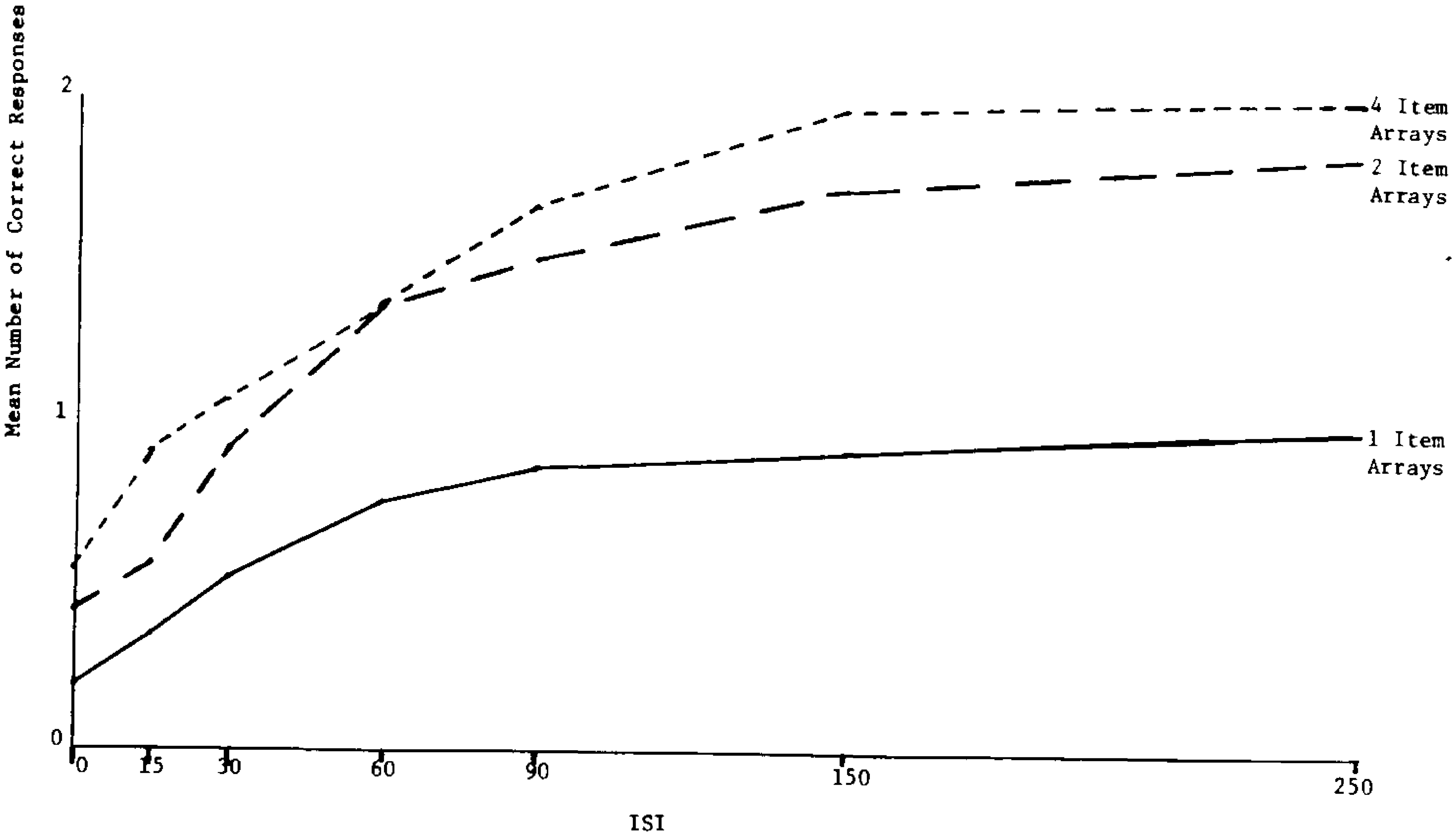
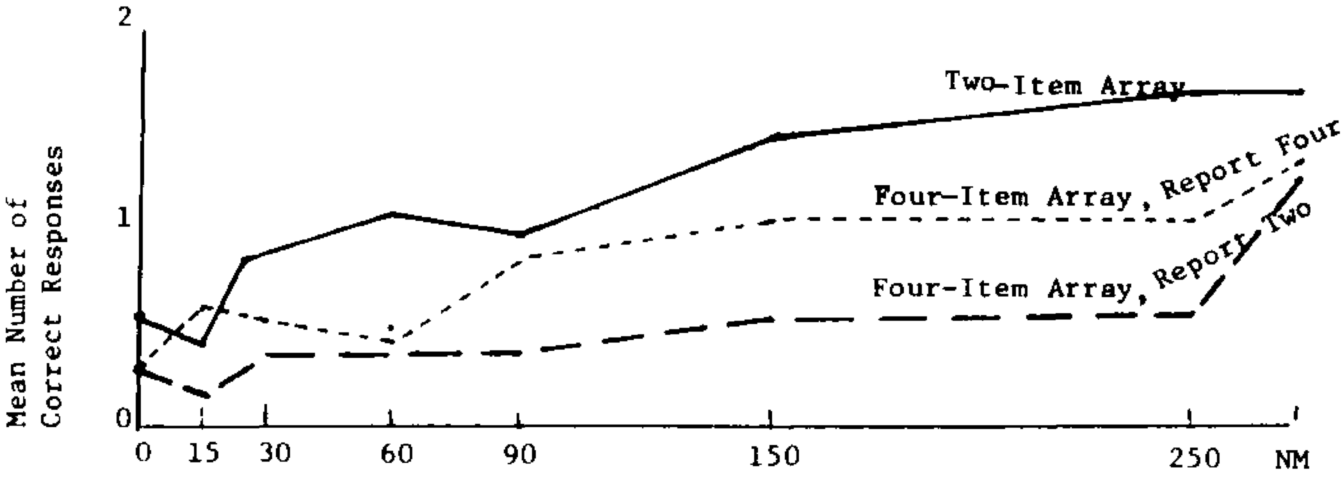


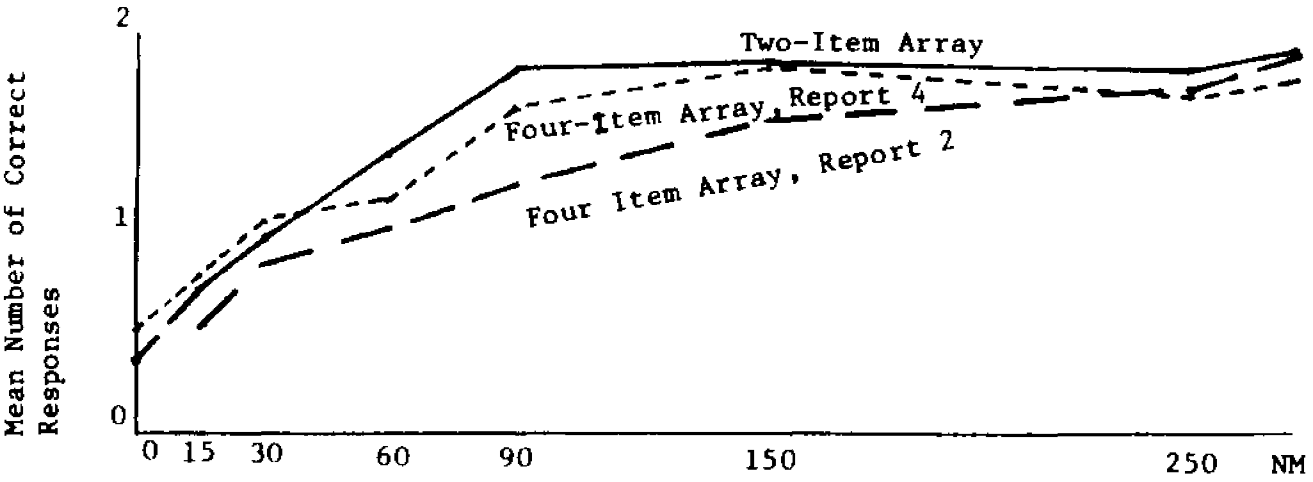
Figure 6. Array Size X ISI Interaction, ANOVA 1



Four-year-olds



Eight-year-olds



Adults

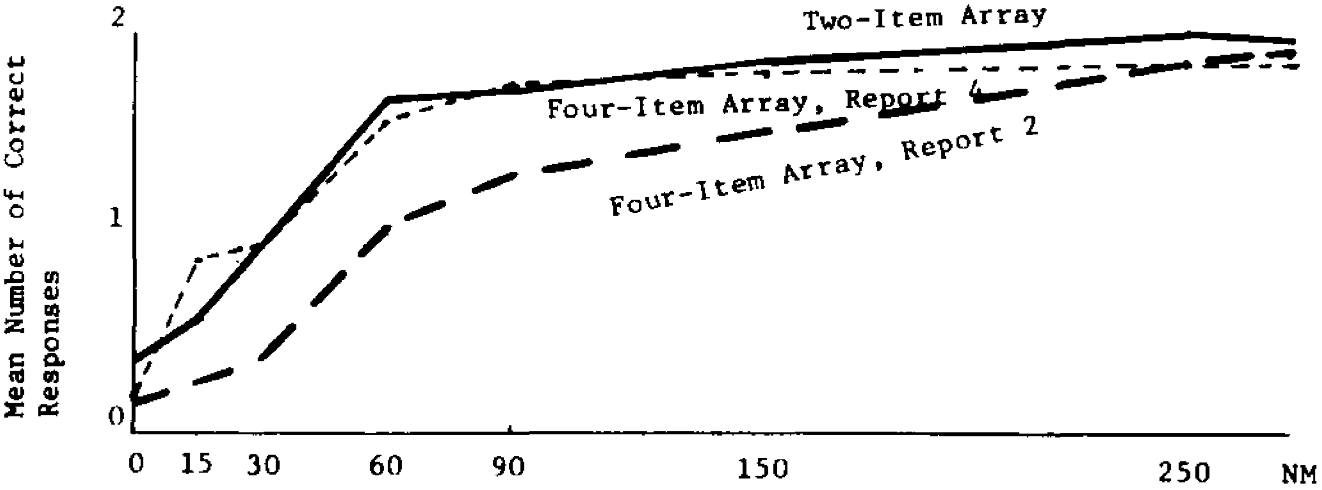


Figure 7. Means at Each ISI for Each Array Condition, by Age Group

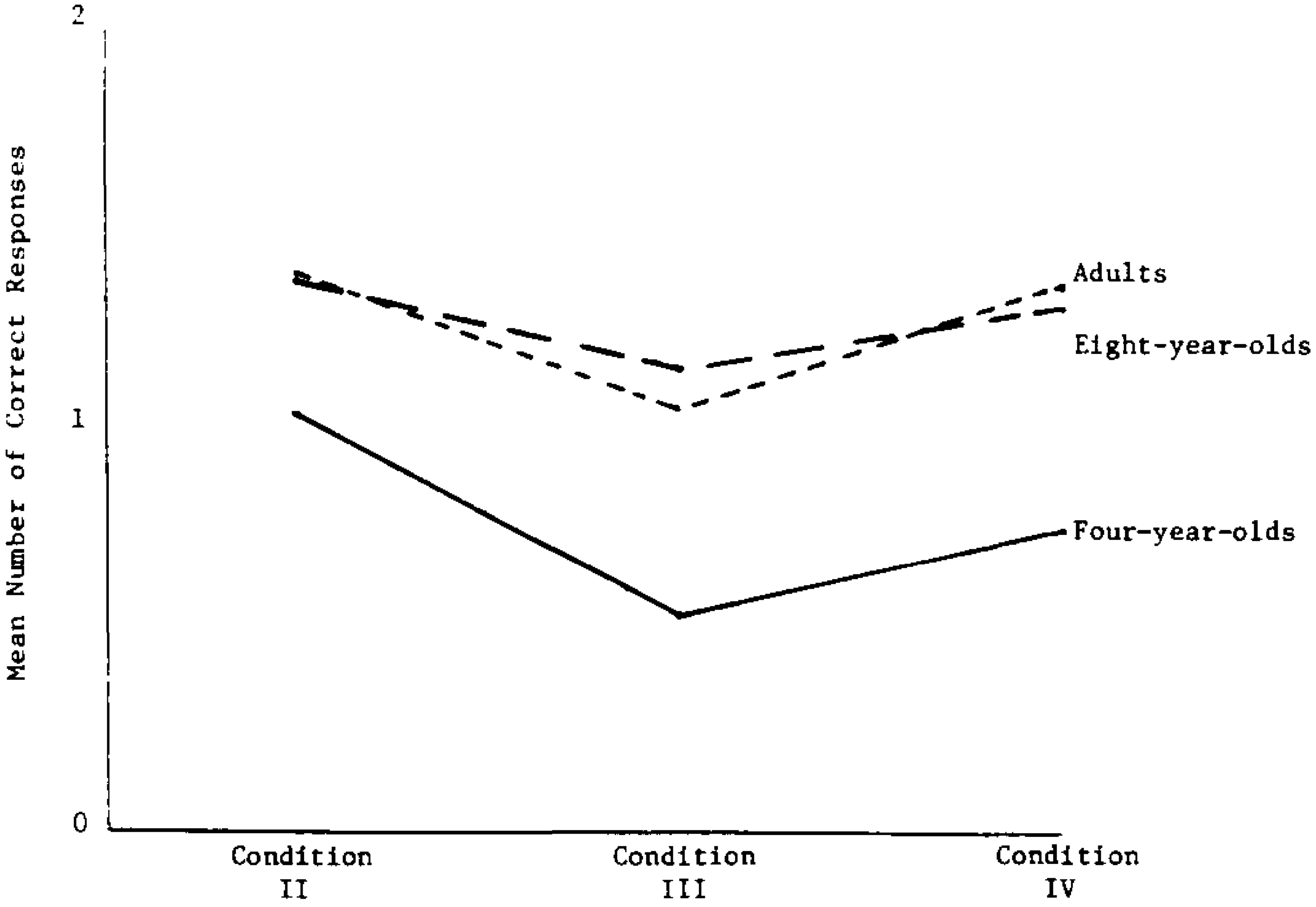


Figure 8. Age x Array Condition Interaction, ANOVA 2

Figure 9. Age x ISI Interaction, ANOVA 2

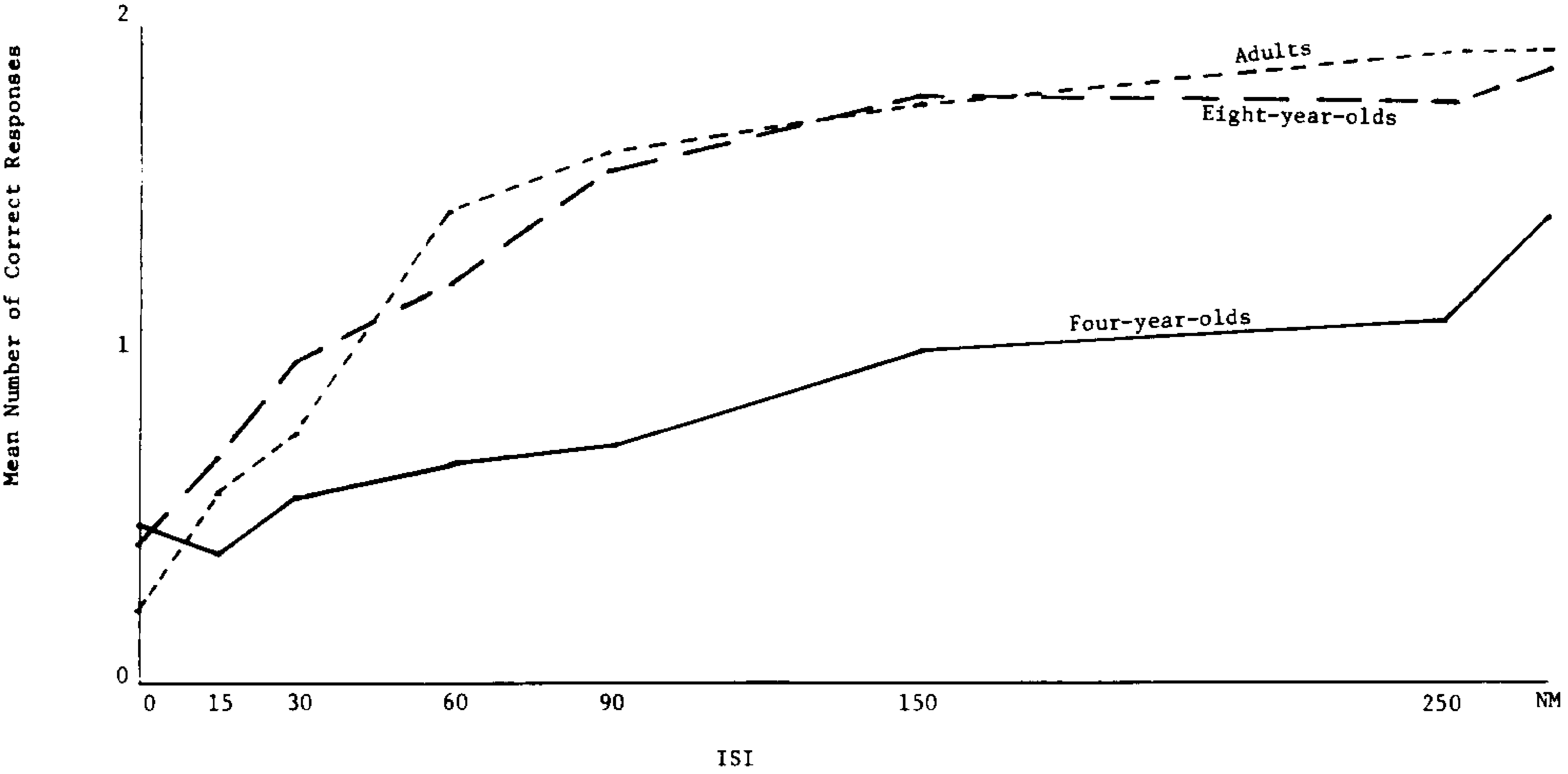
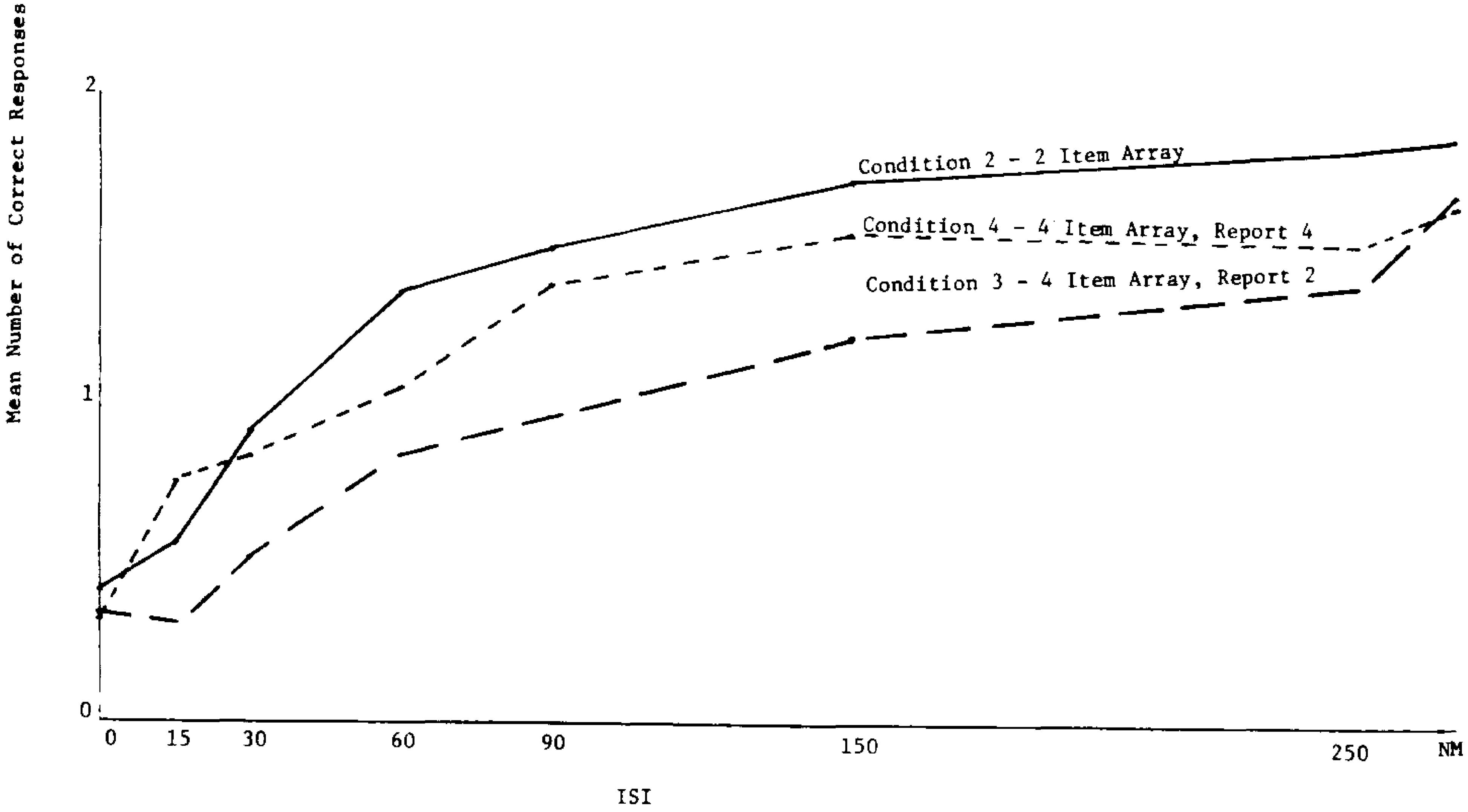


Figure 10. Array Condition x ISI Interaction, ANOVA 2



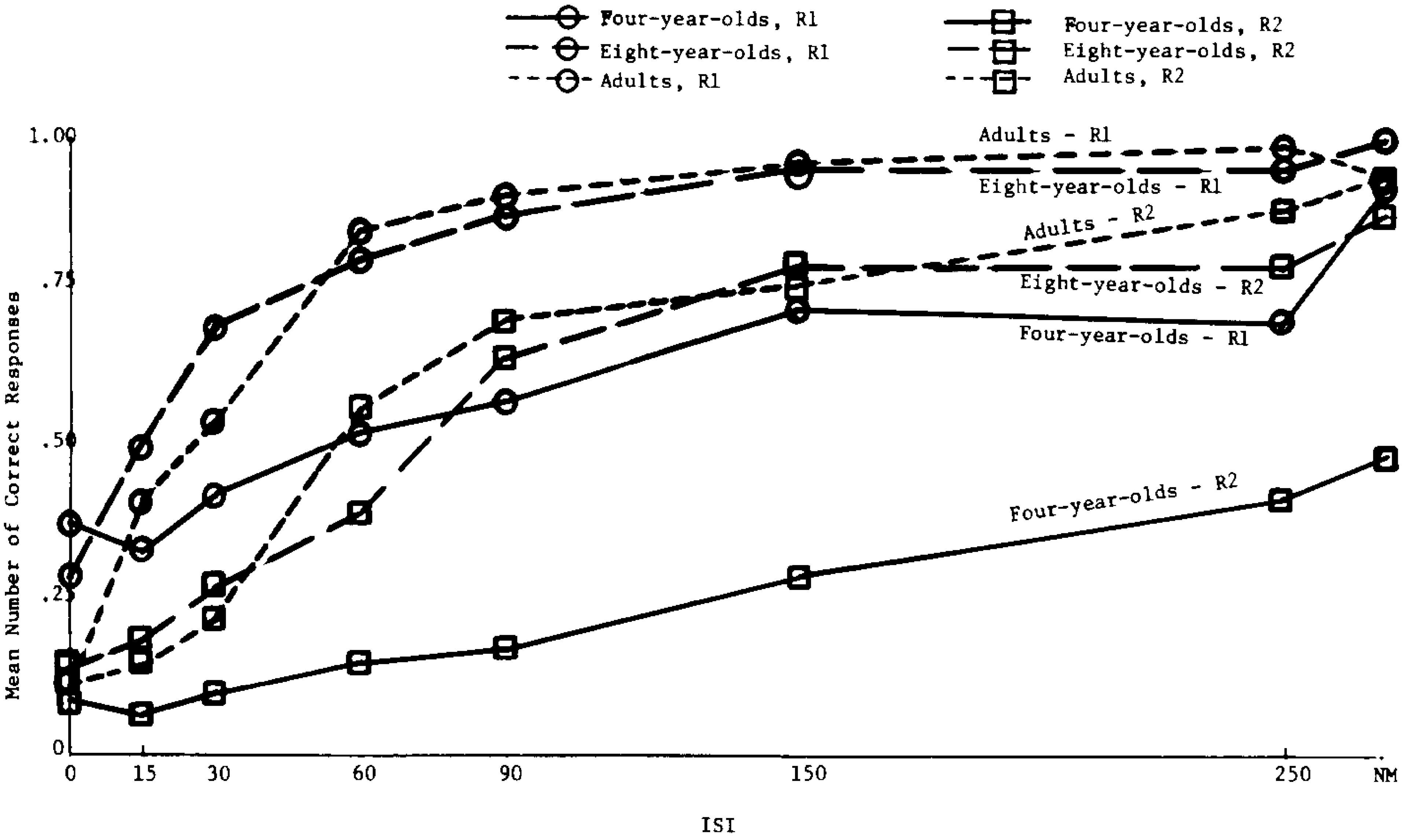


Figure 11. Age x Report Position x ISI Interaction

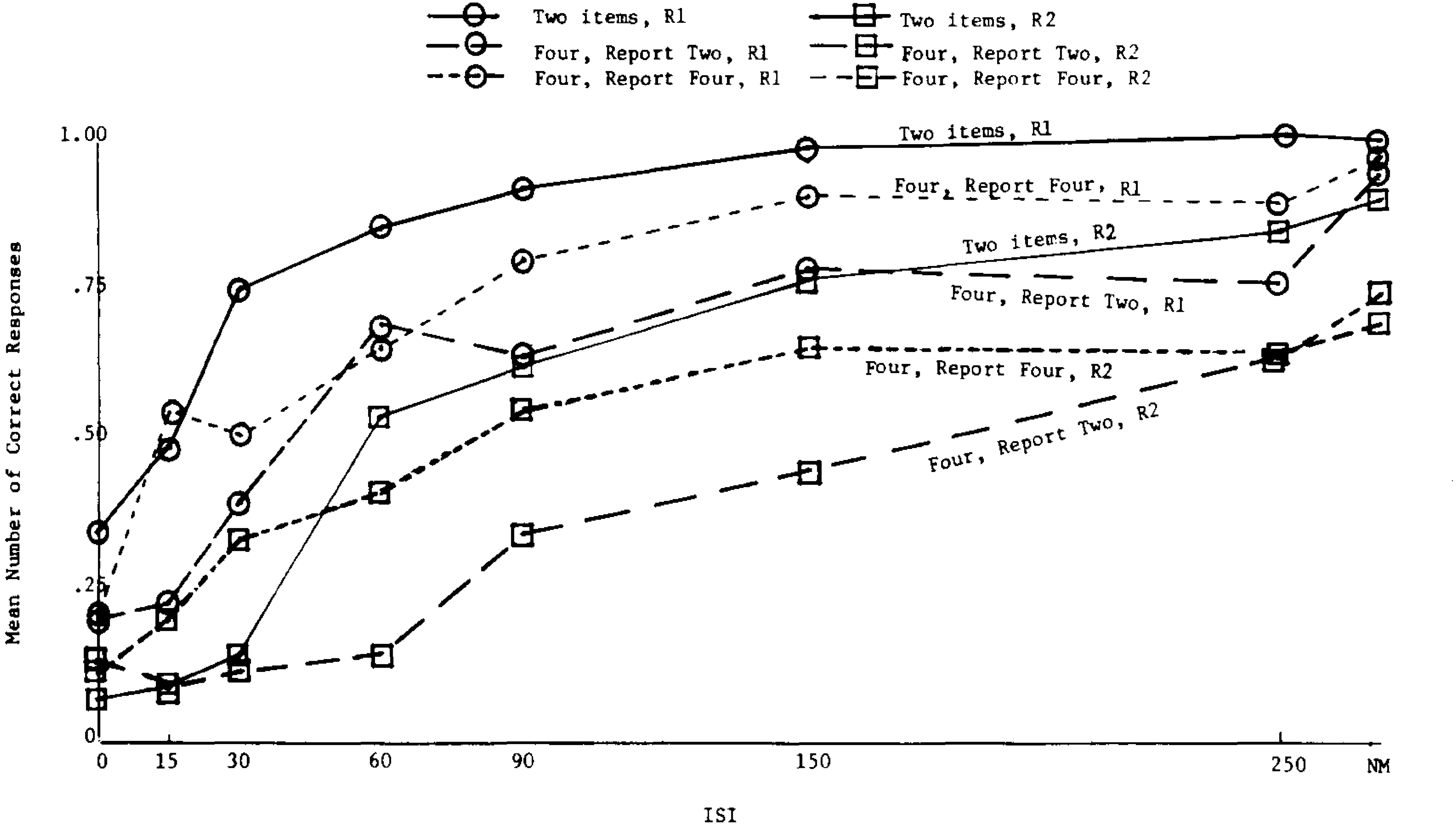


Figure 12. Report Position x Array Condition x ISI Interaction

APPENDIX A

CORRECTION FOR GUESSING

The correction for guessing is based on the assumption that a subject either sees an item perfectly or guesses purely at random. Thus, his total number of correct responses (R) is composed of those items which he actually saw (S) plus a certain proportion (g) of those items which he did not see (N-S). G is equal to the guessing probability. In the case where sampling is with replacement, i.e., items can be repeated both in the stimulus and in the response sequence, and where an item must be reported in the correct position to be correct, the guessing probability is constant for all responses and is 1/n. Thus,

$$R = S + \frac{1}{n}(N-S) \qquad \text{(E1)}$$

This formula can be solved for S, the number actually seen, as follows:

$$R = S + N/n - S/n$$

$$nR = nS + N - S$$

$$nR - N = S(n-1)$$

$$\left(\frac{n}{n-1}\right)R - \frac{N}{n-1} = S$$

$$\left(\frac{n-1+1}{n-1}\right)R - \frac{N}{n-1} = S$$

$$R + \frac{1}{n-1}R - \frac{N}{n-1} = S$$

$$R - \frac{1}{n-1}(N-R) = S \qquad \text{(E2)}$$

This corresponds to the formula used by Sperling and Speelman (1970), which is:

$$\hat{S} = \hat{R} - \frac{1}{n-1}(N-\hat{R}).$$

The cap above R and S designates that these are sample estimates of underlying population values of R and S. In Appendix 1 of their article Sperling and Speelman prove that $\hat{S}$ is an unbiased estimate of S. They also show that, although the formula assumes all-or-none knowledge, it is reasonable to use it when subjects have partial knowledge.

This was the basic formula adopted in the present research to correct for guessing. However, the guessing probability differed, due to the fact that sampling in this situation was without replacement. Ss were not allowed to repeat an item in their response sequence, nor were there any repeated items in the stimulus array. Moreover, an item did not have to be in its correct position to be correct. Ss were not constrained to report items in any order. The guessing probabilities for each response varied with the number of stimuli in the array, the number of the response in the report sequence, and the number of correct responses which preceded a given response. Thus, for single item arrays, the guessing probability for each response was 1/12, since the total set contained twelve items. For two-item arrays, the guessing probability for the first item was 2/12. The probability for the second item was 1/11 if the first item had been correct and 2/11 if the first item had been incorrect. The same probabilities apply to four-item arrays in which Ss were to report only the top and bottom items. For four-item arrays, in which all items were to be reported, the probability of getting the first item correct by chance was 4/12. The probability of getting the second correct by chance was 3/11 if the first response had been correct and 4/11 if the first response had been incorrect. For third responses, the probabilities were 2/10 if the first two responses had been correct, 3/10 if one preceding response had been correct, and 4/10 if no preceding responses had been correct. Similarly, the probabilities for the fourth response were 1/9 if all preceding responses had been correct, 2/9 if three preceding responses had been correct, 3/9 if one preceding response had been correct, and 4/9 if no preceding response had been correct.

These probabilities were each substituted for 1/n in the correction formula. It can be seen from the derivation that the original probability, 1/n, becomes $\frac{1}{n-1}$ in the final formula. In the derivation, the denominator becomes the original denominator minus the original numerator. Thus, substitution of the probabilities given above into Equation 1 increased them substantially. For example, 4/12 became 4/8. Thus, use of this formula can be considered a severe correction for guessing.

Following Equation 2, the number of incorrect responses (N-R) is multiplied by the guessing probability, and the result is subtracted from the number of correct responses (R) to obtain the number actually seen (S). In applying this formula to the present research, N was considered to be the total number of responses in the same position of the report sequence within a block of trials. Thus, N was always equal to 6. The reason that the correction was applied across all responses in a given position of the response sequence was that Ss tended to give their surest responses earlier in the sequence and then guess. Thus, if most of their first and second responses on a four-item block of trials were correct, very little was subtracted from their score for these responses despite the fact that many of their third and fourth responses may have been incorrect.

A specific example of how the guessing correction was applied will be given for a block of six trials in which four items were shown on every trial. Supposing S had five first responses correct, five second responses correct, four third responses correct,and two fourth responses correct. After substitution in Equation 1, the guessing probability for the first response becomes 4/8. Thus, for the first response, the number of incorrect responses (1) is multiplied by .50, and the result is subtracted from the total number correct (5) for a correct score of 4.50. For all other responses in the sequence, the guessing probabilities are weighted. Thus, for the second response, four of the correct responses occurred after a correct first response, while one occurred after an incorrect first response. After substitution in Equation 1, the guessing probability with R1 correct becomes 3/8 or .38, while with R1 incorrect it is 4/7 or .57. Each probability is multiplied by the number of incorrect responses (1). The resulting numbers are then weighted according to the number of times each probability is applicable, i.e., .38 is multiplied by four and .57 by one. Then the obtained figures are added and divided by five. The result (.42) is subtracted from the total number correct (5), for a corrected score of 4.58. Two of the third correct responses were preceded by two correct responses,and two were preceded by one correct response. Thus, the two guessing probabilities, .24 and .43, are both multiplied by the number of incorrect responses (2), and averaged for a total of .68. This is subtracted from the number correct (4),for a corrected score of 3.32. The two correct fourth responses were both preceded by two correct responses. Thus, the number of incorrect responses (4) is multiplied by the guessing probability (.28), and 1.12 is subtracted from 2,for a corrected score of .88. Thus, this subject's score for this block of six trials is adjusted from her original score of 16 correct responses, or an average of 2.67, to a score of 13.28, or an average of 2.21. This example was for a block of trials at a middle ISI, 90 msec. At shorter ISIs, where _S_s had more incorrect responses, the guessing correction was, of course, larger. At longer ISIs, where _S_s had fewer incorrect responses, the guessing correction was smaller. Thus, the underlying assumption is that guessing decreases as accuracy increases. This assumption would seem to be intuitively correct.

The principal weakness of this method of correcting for guessing is that it does not allow for a "good" trial among a series of "bad" trials. Thus, if _S_ had only one response correct on each of five trials but had all four responses correct on the sixth trial, it is possible for her final corrected score to be only 2.30. It is assumed that the guessing level is very high, even for the "good" trial,because of the high number of incorrect responses. However, it is possible that _S_ really attended on that particular trial and actually saw four items. Another weakness is that the guessing probabilities do not take into account correct responses which follow a given response. Thus, the guessing probabilities calculated for the first two response positions, particularly the first, may be somewhat high. However, if subsequent correct responses are to considered in calculating probabilities, then logic such as the following used by Haith (personal communication) must be adopted. Haith asserts that one must consider what else S has on his mind. That is, if he is going to report three correct items later, then those correct responses are not available to him as a first response Thus, Haith calculates chance probabilities in terms of how many other correct responses there are on a trial, regardless of whether they precede or follow the response in question. The probability used to correct a third response is the same as that for a second response if both occur on trials in which two other responses are correct. Positions in the report sequence are not taken into account in calculating probabilities. The drawback in this procedure is that probabilities do not vary as a function of preceding errors. Thus, a fourth response following one correct response and two incorrect responses would be considered as having the same probability of being correct by chance as a second response preceded by a correct first response and followed by two errors. However, it seems more probable, intuitively, that the fourth response after two errors is a guess than that the second response after a correct response is a guess. In general, it seems that Haith's procedure errs in the direction of being too lenient, whereas the procedure adopted in this research errs toward being too conservative. Since the data before chance correction indicated parallel independent processing, it was decided to adopt a severe guessing correction to see if the data would continue to show parallel independent processing. A severe guessing correction affects mainly the scores on four-item, report four, arrays and changes scores on other arrays very minimally. Thus, it is biased in the direction of serial or parallel dependent processing.

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