The Development of Iconic Storage

by

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ABSTRACT

The duration of the icon has been reported to change with age; however, there is disagreement over the direction of the change, with different techniques yielding different results. On the one hand, the duration of the icon has been found to increase with age in studies using the partial-report procedure (Gummerman, Ersoff, Leitner, & Chastain, 1975; Morrison, Holmes, & Haith, 1974; Sheingold, 1973). On the other hand, in studies using the two-flash threshold it has been concluded that the duration of the icon decreases with age (Pollack, Ptashne, & Carter, 1968, 1969; Thor, 1970; Thor & Thor, 1970). Two experiments were performed in an attempt to resolve the contradictory results.

In a partial-report experiment, it was found that the accuracy of 5-year-olds, 9-year-olds, and adults did not differ at delays of the poststimulus cue up to 300 msec, provided that the performance of the three groups was equated at 0 msec delay.

In the second experiment, a direct measure of icon duration required subjects to report whether a disc of light had completely disappeared prior to the appearance of a second, identical stimulus. Again, there was no difference in the performance of the three age groups.

It was concluded that there is no convincing evidence of an age-related change in the duration of the icon.

ACKNOWLEDGEMENTS

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INTRODUCTION

In recent years it has been suggested that the duration of iconic storage changes with age. This study is an examination of such developmental changes. Discussion of the research which stimulated the present investigation will be preceded by a brief review of the concept of iconic storage.

Iconic Storage

The term iconic storage denotes the image, or icon, which persists after the termination of visual stimulation (Neisser, 1967). In the experimental literature, this term has been used interchangeably with sensory register (Atkinson & Shiffrin, 1968), short-term visual storage (Haber, 1969), visual information storage (Sperling, 1963), preperceptual memory (Melton, 1963), etc. In order to be consistent with current usage, the single term iconic storage will be used here.

The classic study of iconic storage was carried out by George Sperling (1960). Sperling was interested in determining how much information could be reported from a briefly-presented array of letters. When subjects were asked to report as many letters as possible from the whole array, the mean number of letters reported, or the immediate-memory span, was only 4.3 letters from a 12-letter array. Sperling reasoned that some of the information in the array may have been forgotten during the report of other portions of the array. To get around this potential confounding, Sperling devised a partial-report procedure in which only a sub-span portion of the array was to be reported on each trial.

Immediately after the presentation of the array, one of three tones indicated to the subject which row of the array was to be reported. In this way Sperling was able to estimate how much of the total array would have been available for report had forgetting not intervened. Sperling found that approximately nine letters were available for report from an array of 12 letters. This value was double the estimate of the immediate-memory span, suggesting that much more information is available than subjects can report. Because the cue was presented <u>after</u> the stimulus array had been exposed, Sperling concluded that the information was available from a persisting memory trace of the stimulus, i.e., the icon.

In order to determine how long the icon lasts, Sperling presented the cue up to 1 sec after stimulus offset. As the delay of the cue was increased, the number of letters correctly reported fell rapidly, from about nine at no delay to approximately 4.5 letters at 1 sec delay. Because the number of letters reported at this delay is approximately the same as the immediate-memory span, Sperling concluded that the icon decays completely within 1 sec after stimulus presentation. Despite procedural differences, Sperling's basic findings have been reported in many subsequent studies (see Dick, 1974 for a review of the literature on iconic storage).

<u>Developmental Changes in Iconic Storage</u>

Recently, researchers have become interested in developmental changes in the duration of the icon. Two quite different procedures have been used with contradictory results. With increasing delays of the post-stimulus cue, the accuracy of partial report has been found to decline more rapidly in 5- and 6-year-old children than in older children and adults (Gummerman, Ersoff, Leitner, & Chastain, 1975; Morrison, Holmes, & Haith, 1974; Sheingold, 1973). From these results, it has been concluded that the icon decays more rapidly in 5-year-olds than in older children and adults.

While the results of partial-report studies suggest an age-related increase in the duration of the icon, studies of the two-flash threshold (TFT) have arrived at the opposite conclusion, i.e., that the duration of the icon decreases with age. In this paradigm, two pulses of light are presented at the same locus in the visual field. The TFT is the shortest interval between the two pulses at which they can be discriminated as two flashes. It is reasoned that two discrete flashes can be perceived only if the icon of the first stimulus has decayed completely before the second stimulus is presented. The TFT was found to decrease monotonically from about 100 msec in 6-year-old children to about 65 msec in 17-year-old subjects (Pollack, Ptashne, & Carter, 1968, 1969; Thor, 1970; Thor & Thor, 1970).

The contradictory results of the partial-report and TFT studies raise the following question: are these two procedures measuring the same process? Other procedures have been used to measure the duration of the icon. An examination of these procedures will help to answer the question.

Measures of the Duration of the Icon

In studies with adult subjects, two general classes of procedures have been used to measure the duration of the icon: those which have been considered "direct" and those which have been considered "indirect." In the direct measures, the subject's task is to report the phenomenal duration of the icon. The subject indicates, in one of a variety of procedures, when the stimulus can no longer be detected. Then the actual stimulus duration (and in some cases, the response latency) is subtracted from the phenomenal duration. The remaining interval is the measure of the duration of the icon.

In the indirect measures, the subject is not required to estimate the duration of the icon; rather, the task involves report of some or all of the contents of the icon. Therefore, the duration of the icon is <u>inferred</u> from task-related performance.

Direct Measures

A number of direct measures of icon duration have been developed independently. All purport to measure the same phenomenon; however, there is a great deal of variability in the results of different measures and even among studies using the same measure.

<u>Threshold of continuity</u>. Haber and Standing (1969) devised one of the first direct measures of the phenomenal duration of the icon. In this procedure, a stimulus and a blank field are repeatedly alternated, and the duration of the blank field is varied until the stimulus appears to be "just phenomenally continuous in time." At suprathreshold intervals, it is assumed that the icon of the stimulus has completely faded before the appearance of the subsequent stimulus. In a number of studies, the <u>threshold of continuity</u> has been found to vary between 100 and 350 msec (Haber & Standing, 1969; Meyer, Lawson, & Cohen, 1975; Standing, Haber, Cataldo, & Sales, 1969). The stimuli and results of all of the studies using direct measures are summarized in Table 1.

Table 1

Summary of Stimuli and Results of Direct Measures of Iconic Storage

Procedure	Authors	Stimuli	Duration (msec)
Threshold of Continuity[a]	Haber & Standing (1969)	50 ml black ring	249
	Haber & Standing (1969)	.5 ml black ring	282
	Haber & Standing (1969)	dark interval	385
	Haber & Standing (1969) (Experiment 2)	20 ml	175-230[b]
	Standing et al. (1969)	rare words	150-300[b]
	Standing et al. (1969)	frequent words	100-350[b]
	Meyer et al. (1975)	gratings	177
(Slits)	Haber & Standing (1969)	50 ml black ring	319
	Haber & Standing (1969)	.5 ml black ring	339
	Haber & Nathanson (1968)	outlined camel	328
(TFT)	Farley (1969)	2 light pulses	47
	Kietzman (1967)	2 light pulses	42, 52[c]
Clicks	Haber & Standing (1970)	3 x 3 array of letters, 5 ml	10-180[b]
	Haber & Standing (1970)	3 x 3 array of letters, dark adaptation	10-410[b]
	Efron (1970)	disc of light 3.4 ft-L	0-120[b]
Reaction-time	Briggs & Kinsbourne (1972)	3 x 3 array of letters	15-75[b]
(Offset-onset)	Erwin & Hershenson (1974)	50 msec letter array	57
	Erwin (1976)	50 msec letter array	68

[a] ISIs only (i.e., excluding stimulus duration); [b] Estimate at lowest and highest stimulus duration, respectively; [c] Data of two subjects.

Using a different procedure to measure the threshold of continuity, Haber has obtained values between 320 and 340 msec (Haber & Nathanson, 1968, Haber & Standing, 1969). A vertical slit is moved back and forth across an outlined stimulus and the rate of oscillation is varied until the stimulus appears to be "both whole and continuous." When the slit is moved slowly, the complete percept of the stimulus disappears between sweeps. When the subject reports that the stimulus appears continuous in time, it is assumed that the icon of the previously-exposed parts of the stimulus has not decayed, and that it appears phenomenally simultaneous with the currently-exposed portions of the stimulus.

A third measure of apparent stimulus continuity is the TFT procedure described earlier. The magnitude of the TFT in adults (40 to 75 msec, e.g., Farley, 1969; Kietzman, 1967) is considerably lower than the 100 to 350 msec estimates obtained with either of the above procedures used to measure the threshold of continuity (see Table 1). As in the case of those two procedures, it is assumed that the icon of the first stimulus has not decayed completely before the second stimulus is presented, resulting in the perception of a single flash of light. However, it is possible that the icon has not completely decayed even when subjects report seeing two flashes. The detection of two flashes may be based on the detection of a decrement in apparent brightness between the two stimuli (Kietzman & Sutton, 1968; Vaughan, 1966). The lower values obtained with this procedure may simply reflect the relatively short interval after the offset of the first stimulus until the decrement in brightness is perceived, and not the time at which the icon has completely decayed.

Calibration of stimulus duration. A second type of direct measure of icon duration requires subjects to indicate the apparent onset of a stimulus and, on separate trials, its apparent offset. Because there are two versions of this procedure which have yielded quite different values, they will be considered separately.

In the first procedure, a brief click is adjusted to coincide with the apparent onset of a stimulus and, on separate trials, with its apparent offset. The interclick interval minus the actual stimulus duration is the estimate of icon duration. Unlike some of the previous procedures, there is more than one value of icon duration. The duration of the icon varies inversely with the actual stimulus duration up to 200 msec (Haber & Standing, 1970). In other words, the estimate of icon duration is about 200 msec with very short stimuli and becomes smaller as the stimulus duration is increased. With stimuli longer than 200 msec, the estimate of poststimulus presistence is close to 0 msec, suggesting that the icon "guarantees an effective stimulus duration" of at least 200 msec. Efron (1970) reported similar results, except his estimates of icon duration were approximately 70 msec smaller. Both of these estimates of icon duration are shorter than some of the estimates obtained with the threshold of continuity procedure.

In the second procedure, the subject is required to release a telegraph key as soon as the stimulus is perceived and, on separate trials, when it is no longer perceived. The duration of the icon is determined by subtracting the mean reaction time to stimulus onset from the reaction time to stimulus offset. The difference is about 70 msec (Briggs & Kinsbourne, 1972; Erwin, 1976; Erwin & Hershenson, 1974), a value that is considerably smaller than any of the preceding measures other than the TFT.

Briggs and Kinsbourne also reported that the duration of the icon is inversely related to stimulus duration up to about 400 msec, beyond which icon duration remains asymptotic at less than 30 msec. No explanation was given for the much smaller estimates of icon duration obtained with this procedure.

Indirect Measures

Partial-report studies. The partial-report technique has been the most frequently-used procedure for studying iconic storage. The assumption underlying this procedure is that the icon is available to the subject as long as its contents can be identified. Averbach and Coriell (1961) estimated that the duration of the icon is between 150 and 250 msec. This value coincides with many of the direct measures of icon duration.

Integration studies. Another indirect measure of icon duration is the maximum interval over which information from two successive stimuli can be integrated. For example, Eriksen and Collins (1967) presented two dot patterns at varying interstimulus intervals (ISIs). Individually, neither stimulus could be identified; however, when superimposed, a trigram such as VOH, could be recognized. The accuracy of recognition decreased as the ISI became longer, until asymptote was reached between 100 and 300 msec. Ross and Hogben (1974) used a similar procedure and found that a figure in depth could be identified from a pair of successively-presented random dot stereograms (Julesz, 1960) up to 72 or 144 msec ISI, depending on the procedure used.

While these values are within the range of other measures of icon duration, it is unclear whether the results reflect icon duration alone.

It is possible that the integration time includes not only the icon decay time but also the time required for stimulus integration (see Eriksen & Collins, 1968). "Perception time for stereopsis" has been estimated as 50 msec (Julesz, 1971), and this interval may be part of the estimate of icon duration obtained by Ross and Hogben. Therefore, this procedure may overestimate the duration of the icon by the amount of time required for integration or stereopsis.

Conclusion

The examination of different measures of icon duration was prompted by the contradictory results obtained in the studies using the partial-report and TFT procedures to measure the duration of the icon in children and adults. The review of measures used in adult studies suggests that the TFT and reaction-time results might be estimates of a different process than the remaining direct measures. Also, there was a great deal of variability among the results of the other direct measures. Therefore, it was decided to use more than one measure of icon duration. One direct and one indirect measure were chosen and it was determined whether the relationship between chronological age and icon duration is consistent in the two procedures.

Choice of Measures

Two criteria were used to select measures for examining developmental changes in the duration of the icon. First of all, any measures with results that deviated greatly from the majority of adult studies, i.e., in the range of 200 to 350 msec, were eliminated from consideration. These included the TFT, reaction-time, and stimulus integration procedures. Secondly, it was necessary to choose procedures which would be appropriate for use with children. For example, Haber and Standing (1970) reported that it took 4 hours of training with adults to achieve reliable results with the calibration of clicks to stimulus onset and offset. It might take even longer for children to learn to perform the task, because of the difficulties they might encounter with cross-modal comparisons (e.g., Rudel & Teuber, 1964; but see Vande Voort, Senf, & Benton, 1972).

In the case of the indirect measure, the partial-report procedure was selected. There is an abundance of research with adults using this procedure and a great deal is known about the variables which influence partial report. In addition, previous studies (e.g., Sheingold, 1973) have used this procedure with children as young as 5 years of age. However, there are some methodological problems with the previous partial-report studies using children. These problems and modifications in the procedure to eliminate them will be discussed in Experiment 1.

The direct measure was a modification of Haber and Standing's (1969) threshold of continuity procedure. It was expected that the concept of apparent continuity of a stimulus might be difficult for children. Therefore, subjects were required to indicate whether a stimulus had completely faded before a subsequent stimulus was presented. The procedure encouraged the subjects to adopt a stable criterion of icon decay. A complete description of the method will be given in Experiment 2.

EXPERIMENT 1

The partial-report procedure was the indirect measure chosen to determine whether the duration of the icon changes with age. In previous developmental studies using this procedure, there were a number of problems which make it difficult to draw firm conclusions about the results. In those studies, the stimulus array was presented for the same duration to subjects of all ages. Two important consequences arise from this manipulation. In the first place, the accuracy of partial report at 0 msec ISI was close to 100% for the older subjects while that of the 5-year-old children was up to 25% lower (e.g., Morrison et al., 1974; Sheingold, 1973). Thus the obtained interaction between age and ISI is confounded by a potential ceiling effect on the report of the older subjects (see Belmont & Butterfield, 1969). Even in the absence of a ceiling effect, the age-related difference in performance at no delay (e.g., Gummerman et al., 1975) might have influenced the rate of decline in accuracy of report over delays (see Keppel, 1965; Underwood, 1964). In the present study, the duration of the stimulus array was adjusted in practice sessions until a criterion of 75% correct report was achieved at 0 msec ISI. It was anticipated that this criterion would be sufficiently below ceiling to allow any potential interaction between age and ISI to appear. Performance of individual subjects has been equated in this manner in previous partial-report studies with adults (e.g., Eriksen & Rohrbaugh, 1970; Eriksen & Steffy, 1964; Haber, 1968; Spencer, 1969).

A further deficiency in previous partial-report studies has been the use of a small number of practice sessions. For example, Sheingold (1973) gave her subjects extensive practice only at the beginning of the first session. Only a single practice session was included in the research designs of Gummerman et al. (1975) and Morrison et al. (1974). It is possible that the performance of young children differed from that of older subjects in those studies because children might take longer than adults to learn how to perform the task. In the present study, a great deal of practice was given to subjects of all ages before the test phase was begun. The test trials were given only after subjects had achieved the criterion level of performance.

A third problem with most of the previous partial-report studies with children is the small number of trials given at each delay of the post-stimulus cue. For example, Sheingold (1973) ran only 15 trials per delay, which may have resulted in the unsystematic pattern of differences among age groups over delays.[1] In the present study, over three times as many trials were given at each delay, compared to the studies of Sheingold (1973) and Morrison et al. (1974).

Another source of confounding in previous partial-report studies is the order of presentation of ISIs. Both Sheingold (1973) and Morrison et al. (1974) used an ascending series of ISIs in each session. If the longest ISIs are always presented at the end of a session, as in those studies, any decrements in performance over increasing ISIs may, in part, be due to increased fatigue, especially in the youngest subjects. By the same token, the presentation of the smallest ISIs at the beginning of every session confounds warmup effect with ISIs. Sheingold did find a

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[1]In Sheingold (1973) the 5-year-olds were significantly less accurate than adults at some delays (0, 100, 250, and 1000 msec) but not at others (50, 150, 200, and 500 msec).

significant order effect and a significant interaction between order and ISI. In the present study, the effects of warmup and fatigue were distributed across ISIs by counterbalancing the order of presentation of ISIs within and between sessions in a Latin Square design.

Method

Subjects

Four males and four females served as subjects in each of three age groups: adults, 9-year-olds, and 5-year-olds. The mean ages of the three groups were: 23.1 years, 9.1 years, and 5.8 years, respectively. The adults were unpaid volunteers, solicited from summer school classes at Adelphi University, Garden City, N. Y.; the 9-year-olds had recently completed third grade at St. Thomas the Apostle School, in Hempstead, N. Y.; and the youngest children had completed kindergarten at Cathedral Nursery School, in Garden City, N. Y. When the latter sample was exhausted, friends of these children were tested. Children with behavioural problems, as determined by their teachers, were not tested. Prior to the start of the experiment, all subjects were screened for binocular distance acuity of 20/29 or better with a Bausch and Lomb Modified Orthorater.

Apparatus and Stimulus Materials

A three-field tachistoscope (Scientific Prototype, Model GB) was used for stimulus presentation. In each field, a stimulus card could be viewed through a circular area 4^o in diameter, cut out from a cardboard stimulus holder painted flat black. Each of 24 stimulus cards contained a circular array of eight black, outlined geometric shapes, arranged according to the rows of three balanced 8 x 8 Latin Squares (Table 2). The shapes were: the numbers 1 and 7 (Letraset No. 258); square, circle, and triangle (Letraset No. 2453); dollar sign (Letraset No. 1281); asterisk (Para-tipe No. 55055); and a cross, constructed of thin black lines (see Figure 1 for a sample array). Viewed at a distance of 1.27 m, the numbers and shapes were all 13.2' of arc high, the 7 was 6.5' wide, the 1 was 1.2' wide, and all of the other stimuli were 13.2' wide. The outer diameter of the circular array was 2^{o}, and each array appeared on a white 10.2 x 15.2 cm index card, as did each indicator. The indicator was a black teardrop (Letraset No. S6408), 15' long, situated at the centre of the stimulus field, 35.4' from the inner edge of the stimulus element. There were eight indicator cards; one for each stimulus position.

In order to keep luminance-summation/contrast-reduction constant (Eriksen, 1966), on simultaneous presentations the indicator appeared on a transparent sheet of plastic which was superimposed on the stimulus array in Field 1. Each stimulus position and each shape appeared randomly as the target stimulus an equal number of times each session.

The luminance of Field 1 was set at 57.97 cd/m^2, that of Field 2 was 59.54 cd/m^2, and the adaptation field was 54.30 cd/m^2, as measured with an SEI photometer and a blank white card in each field. A tiny black fixation dot, 4' in diameter, appeared in the centre of a circular white adaptation field 4^{o} in diameter.

A 10.2 x 15.2 cm white response card was mounted horizontally on the tachistoscope, to the right of the viewing hood. The eight stimuli, each

Table 2

The Stimulus Arrays in Experiment 1

Array No.	Serial Position[a]
1	8 7 2 5 1 4 6 3
2	7 5 8 4 2 3 1 6
3	5 4 7 3 8 6 2 1
4	4 3 5 6 7 1 8 2
5	3 6 2 1 5 2 7 8
6	6 1 3 2 4 8 5 7
7	1 2 6 8 3 7 4 5
8	2 8 1 7 6 5 3 4
9	6 3 7 8 1 2 4 5
10	3 8 6 2 7 5 1 4
11	8 2 3 5 6 4 7 1
12	2 5 8 4 3 1 6 7
13	5 4 2 1 8 7 3 6
14	4 1 5 7 2 6 8 3
15	1 7 4 6 5 3 2 8
16	7 6 1 3 4 8 5 2
17	1 4 6 5 7 3 8 2
18	4 5 1 3 6 2 7 8
19	5 3 4 2 1 8 6 7
20	3 2 5 8 4 7 1 6
21	2 8 3 7 5 6 4 1
22	8 7 2 6 3 1 5 4
23	7 6 8 1 2 4 3 5
24	6 1 7 4 8 5 2 3

[a]Serial positions in clockwise order, with position 1 at 12 o'clock and position 8 at 10:30. Stimulus 1 represents one; 2: square; 3: triangle; 4: circle; 5: cross; 6: asterisk; 7: seven; 8: dollar.

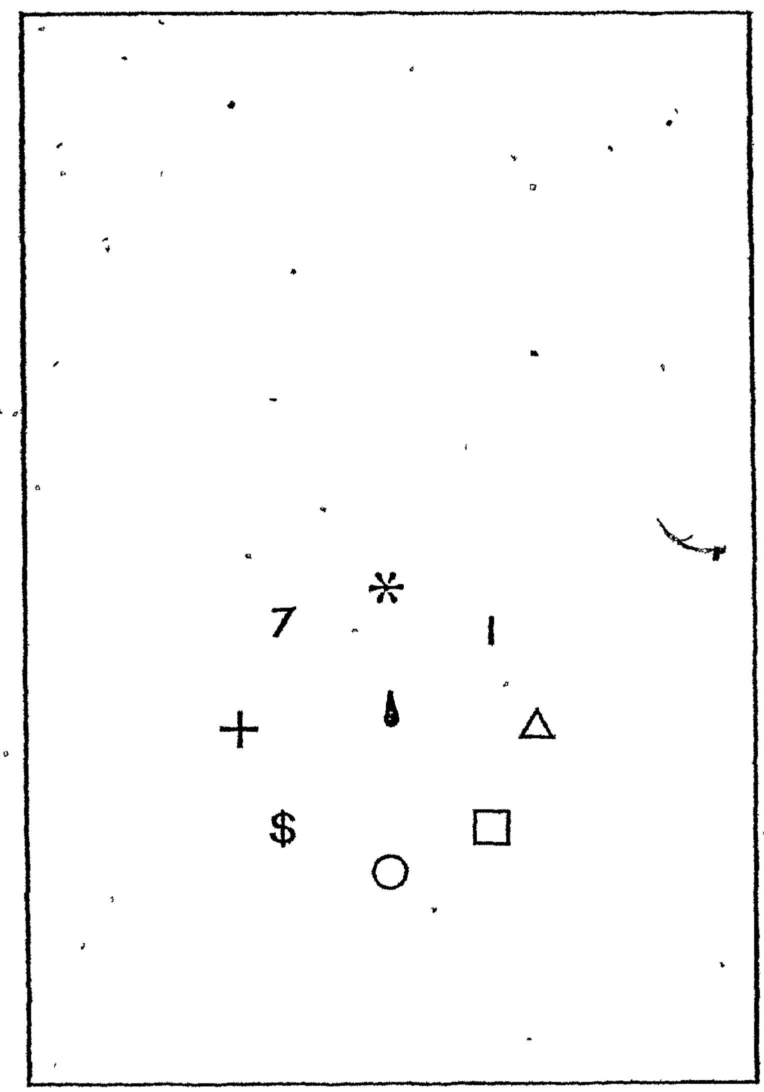

Figure 1. Sample array of geometric stimuli and indicator: Experiment 1.

approximately 1.2° square,[2] were arranged in two rows of four stimuli. The response card was kept clean by covering it with a transparent sheet of plastic which was wiped after each subject completed a session. The order of presentation of ISIs within and between sessions was determined from eight 4 x 4 Latin Squares (Table 3).

Procedure

Subjects were individually tested in a quiet, temperature-controlled laboratory at Adelphi University.

Practice sessions. At the beginning of the first practice session, a stimulus card and transparent indicator card were exposed in Field 1 and the subject was asked to show which stimulus had been indicated by the teardrop by pointing at it on the response card. Additional examples were presented until it was clear that the task was understood, i.e., until performance was errorless. On each trial, the subject was instructed to "look at the [fixation] dot," and on the command "go," the experimenter pressed a hand switch to expose the stimulus array and indicator. The adaptation field then reappeared and remained exposed until the next trial. Subjects were encouraged to respond on every trial and to guess, if necessary. The stimulus- and indicator-cards were then changed and a new trial was initiated. After every 12 trials, the children were given checkers for correct responses. The checkers could be exchanged for a small toy after each session. A 5-min rest was given after every 24 trials.

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[2] The visual angle subtended by the stimuli on the response card cannot be specified because the distance between the card and the subjects probably varied between trials and among subjects.

Table 3

Balanced Latin Squares used in Experiment 1; rows represent sessions, columns represent the order of presentation of ISIs, and letters are the ISIs: A=0; B=50; C=150; D=300 msec.

1	2	3	4
A B C D	B A C D	C A B D	D B C A
B D A C	A D B C	D B A C	C D A B
C A D B	D C A B	A D C B	B A D C
D C B A	C B D A	B C D A	A C B D

5	6	7	8
B D C A	A D C B	D A C B	C B D A
D A B C	C A B D	B C A D	A D B C
A C D B	B C D A	C D B A	D C A B
C B A D	D B A C	A B D C	B A C D

The following procedure was used to adjust the stimulus duration to achieve the criterion level of performance. Initially, the stimulus array and indicator were presented simultaneously for 250 msec. On each trial, if the subject did not correctly report the target stimulus, an additional correction trial was given. If the response was still incorrect, the subject was informed of the correct response. The stimulus duration was gradually reduced in steps of 50 msec. if the subject achieved at least four correct trials in a block of six trials. Otherwise, an additional block of six trials was presented at the same stimulus duration. If the subject's performance still did not exceed four correct responses out of six trials, the stimulus duration was increased by 50 msec on the next block of trials. This procedure was followed until a stimulus duration of 50 msec was reached. The indicator was then presented for 50 msec at 0 msec ISI, i.e., presentations were now successive. For the remainder of the practice sessions, the stimulus duration was reduced only if performance equalled or exceeded 75% correct on each block of 12 trials. At stimulus durations below 50 msec, the indicator was presented for the same duration as the stimulus array. This procedure was repeated until the subject achieved 75% correct in at least two consecutive blocks of 12 trials.

The general procedure was modified somewhat for the 5-year-old children. In a pilot study, the youngest children found the task difficult when the initial stimulus durations were as short as 250 msec. Therefore, at the beginning of the first session, the stimulus array and indicator were presented simultaneously for 1 sec. The stimulus duration was reduced in 100-msec steps only if the child's performance was perfect.

Once the child began to make errors, the stimulus duration was decreased by 50 msec at a time, provided that the child achieved at least eight correct responses in each block of 12 trials. Otherwise, the stimulus duration was increased by 50-msec steps until performance improved. As the stimulus duration became shorter, the reductions in duration between blocks of trials was decreased to 25 msec and, in some cases, to 10 msec, depending on the individual subject's performance. Once the exposure duration could no longer be reduced without a concomitant decrease in accuracy of report, the indicator was presented at 0 msec ISI and the exposure duration of the stimulus array was adjusted to yield 75% correct report. At successive presentations, the indicator duration was 50 msec for all stimulus durations above 50 msec, and equal to the stimulus duration if it was below 50 msec.

Test sessions. At the beginning of each test session, the stimulus duration was recalibrated, in the following manner: if performance had exceeded the 75% criterion at 0 msec ISI in the previous session or in 12 warmup trials at the beginning of the given session, the stimulus duration was reduced by 5 msec. Similarly, if performance had fallen below criterion, the duration was increased by 5 msec. Once determined, the stimulus duration remained constant for the remainder of the session. At stimulus durations below 50 msec, the duration of the indicator was equal to the stimulus duration. At stimulus durations above 50 msec, the indicator duration was kept constant at 50 msec.

The order of presentation of delays was counterbalanced within and between sessions in the following manner: four ISIs, 0, 50, 150, and 300 msec, were presented in blocks of 15 trials. The first three trials in each block were warmups, followed by 12 test trials. The order of presentation of ISIs was determined by one row of a balanced 4 x 4 Latin Square, with each ISI preceding and following every other ISI once, and only once, in each Square. Within each age group, each subject was run according to a different Latin Square, with the four rows representing sessions and the columns representing the order of presentation of ISIs within sessions (see Table 3). A total of 72 trials (including 24 warmups and 48 test trials) were presented each session, for all age groups, with the set of stimulus cards randomly presented in three blocks of 24 trials. Each indicator position was presented randomly once in each eight-trial block. Sessions lasted from 45 to 60 min, with a 1-min rest after the first and third blocks of ISIs. All subjects received the same randomly-determined order of presentation of stimulus arrays and indicator positions each session, with a different order each session. After each ISI, the children were rewarded with checkers for correct responses.

Results

The number of correct responses obtained by each subject at each ISI was analyzed, and the mean percent correct for all three age groups is shown in Figure 2. It is obvious that the matching procedure was successful in equating the performance of the subjects in the three age groups at 75% correct at 0 msec ISI. The mean number of practice sessions to establish criterion was 2.4 sessions for both the adults and 8-year-olds, and 4.4 sessions for the 5-year-olds.[3]

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[3] One 5-year-old girl and one 8-year-old girl performed considerably

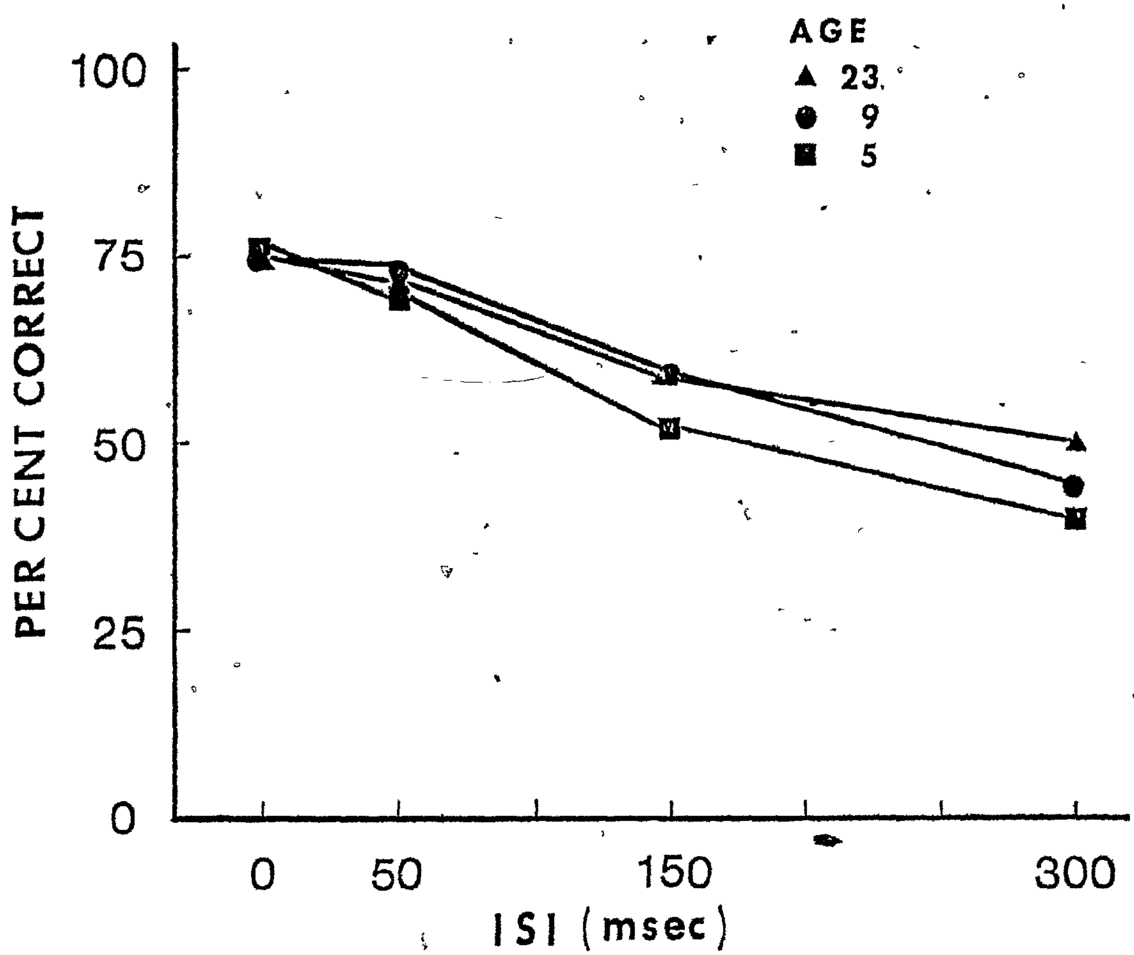

Figure 2. Mean per cent correct partial report over ISIs: Experiment 1.

The mean stimulus durations to achieve equal performance at 0 msec ISI were: 29.3 msec for the adults; 22.8 msec for the 9-year-olds; and 66.9 msec for the 5-year-olds. A one-way analysis of variance revealed that these durations were significantly different, $F\ (2, 21) = 17.78$, $p < .01$ (Table 4). Comparisons among means (see Rodger, 1974) showed that the stimulus presentation time for the 5-year-old children was significantly longer than for the older subjects, whose times were not significantly different from each other (Table 5). A possible explanation for the longer stimulus duration required by the 5-year-olds is that their acuity may be poorer than the older subjects and that they have greater difficulty reading the stimuli at shorter stimulus durations. However, analysis of variance found no difference in the acuity of the subjects in the three age groups, $F\ (2, 21) = .96$, $p > .05$.

The variable of major interest is the rate of decline in performance over ISIs. A 3(age) x 2(sex) x 8 (Latin Squares) x 4(ISIs) x 4(sessions) analysis of variance was calculated on the number of correct responses at each ISI (Table 6). The only significant effect was ISI, $F\ (3, 324) = 101.38$, $p < .01$, and it is apparent from Figure 2 that performance

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below 75% correct in at least five practice sessions and were replaced by other subjects. One 5-year-old boy achieved 83% correct at the end of four practice sessions and was then given the test sessions, under the assumption that the daily calibration of stimulus duration would reduce his performance to criterion. Unfortunately, this did not occur, and he achieved 93% correct performance at 0 msec ISI in the four test sessions, at a mean stimulus duration of 27 msec. This failure to achieve criterion was probably due to the conservative calibration procedure in which the stimulus duration was reduced by small steps of 5 to 10 msec; past experience dictated caution when calibrating the duration, especially for the youngest subjects. This subject's data were not included in the results, because he exceeded criterion, and another subject was run in his place. Parenthetically, it may be added that this subject was reading at third-grade level, despite the fact that he was about to enter grade one; he was well above average in intellectual ability.

Table 4

Analysis of Variance of Stimulus Presentation Times:

Experiment 1

Source	df	SS	MS	F
Age	2	9,859.46	4,929.73	17.78 *
Error	21	5,823.79	277.32	
Total	23	15,940.16		

* $p < .01$

Table 5

Multiple Comparisons of Stimulus Duration:

Experiment 1

Age (years):	5	9	23
Stimulus Duration (msec):	66.9	22.8	29.3
Coefficients of Comparisons:	0	+1	-1
	-2	+1	+1

Comparing Group 9 vs. 23 years:

$\underline{F}$ (2, 21) = 0.30

Comparing Group 5 vs. 9 and 23 years:

$\underline{F}$ (2, 21) = 16.05 *

Formula Adapted from Rodger (1974):

$$\underline{F} = \frac{\underline{n}\ (\Sigma c_j \overline{X}_j)^2}{\nu_1 (\Sigma c_j^{\,2})\ MS_E}\ \text{, with } \nu_1,\ \nu_2\ \underline{df}$$

$\underline{F}$ [.01] (2, 20) = 4.872

* $\underline{p} < .01$

Table 6

Analysis of Variance on the Number of Correct Responses:

Experiment 1

Source	df	SS	MS	F
Between Subjects	23	261.21		
Age (A)	2	19.94	9.97	0.82
Sex (Sx)	1	3.38	3.38	0.28
A x Sx	2	34.92	16.46	1.35
Latin Squares	7	68.58	9.80	0.80
$Error_B$	11	134.39	12.22	
Within Subjects	360	1,808.13		
ISI (I)	3	829.21	276.40	101.38 *
Sessions (Ss)	3	2.15	0.72	0.26
A x I	6	18.18	3.03	1.11
I x Sx	3	3.25	1.08	0.40
A x I x Sx	6	16.70	2.78	1.02
A x Ss	6	23.18	3.86	1.42
Ss x Sx	3	7.15	2.38	0.87
A x Ss x Sx	6	24.99	4.17	1.53
$Error_W$	324	883.31	2.73	
Total	383	2,069.33		

* $p < .01$

decreased monotonically over ISIs. Multiple comparisons among means revealed that performance at each ISI was significantly greater than that at the next-highest ISI (Table 7). Of particular interest is that fact that the age x ISI interaction was not statistically significant $F(6, 324) = 1.11$, $p > .05$ (Table 6), i.e., accuracy does not differentially decline over ISIs in the three age groups.

Because the order of presentation of ISIs within sessions is confounded in the present design with the ISI x sessions interaction, a separate analysis of variance was calculated on the within-subjects partition of variance, substituting order for ISIs. None of the main effects nor any of the interactions were statistically significant (Table 8). In other words, the Latin Square design effectively counterbalanced the order of ISIs within sessions.

Discussion

A number of clear results have emerged from this experiment. At 0 msec ISI, the 5-year-old children required significantly longer stimulus presentations to achieve the same level of partial-report performance as the older children and adults. However, once their performance was equated at that ISI, the youngest subjects were as adept as both older age groups in extracting information from the decaying icon, up to 300 msec after stimulus presentation.

Previous developmental studies (Gummerman et al., 1975; Morrison et al., 1974; Sheingold, 1973) have found that the accuracy of partial report in 5-year-olds declines more rapidly over delays of the poststimulus cue than in older subjects. Yet, the present study revealed that

Table 7

Multiple Comparisons of ISIs: Experiment 1

ISI (msec):	0	50	150	300
$\overline{X}$ correct: (out of 48)	36.46	34.21	27.04	21.63
Coefficients of Comparisons:	+1	−1	0	0
	0	+1	−1	0
	0	0	+1	−1

Comparing 0 vs. 50 msec ISI:

$$\underline{F}\ (3, 324) = 7.42\ *$$

Comparing 50 vs. 150 msec ISI:

$$\underline{F}\ (3, 324) = 75.32\ *$$

Comparing 150 vs. 300 msec ISI:

$$\underline{F}\ (3, 324) = 42.88\ *$$

$\underline{F}\ [.01]\ (3, \infty) = 2.994$

* $\underline{p} < .01$

Table 8

Analysis of Variance on the Within Subjects Components of Variance, Substituting Order for ISI: Experiment 1

Source	df	SS	MS	F
Within Subjects	360	1,808.13		
Order (O)	3	26.81	8.94	1.70
Sessions (Ss)	3	2.15	0.72	0.14
Age (A) x O	6	11.33	1.89	0.36
O x Sex (Sx)	3	4.98	1.66	0.31
A x O x Sx	6	0.60	1.10	0.02
A x Sx	6	23.18	3.86	0.73
Sx x Sx	3	7.15	2.38	0.45
A x Sx x Sx	6	24.99	4.17	0.79
$Error_W$	324	1,706.94	5.27	

5-year-olds are as accurate as older subjects up to 300 msec ISI. The discrepancy in results may be due to a number of improvements in the methodology of the present study. Increasing the number of practice sessions and equating the performance of subjects of all three age groups at a sub-ceiling level at 0 msec ISI avoided the artifactual interaction between age and ISIs which probably occurred in the earlier studies. A further advantage of equating the performance of all subjects a 0 msec ISI was the elimination of the influence of any age-related differences in the time to detect the cue and read out the stimulus (see Gummerman et al., 1975). In addition, confounding of warmup and fatigue effects with ISIs was avoided in the present study by carefully counterbalancing the order of presentation of ISIs within sessions. Another improvement in the present study was the large increase in the number of trials (48) at each ISI, making the present results less susceptible to chance variation than previous partial-report studies (e.g., Sheingold, 1973).

It is tempting to conclude that the icon decays at the same rate for subjects from 5 years of age to college students; however, such a conclusion is premature. It might be argued that the additional 35 to 45 msec required by the youngest subjects to achieve equal performance with older subjects may have increased the duration of the icon. However, previous research with adults suggests that the icon becomes shorter with longer stimulus durations (Briggs & Kinsbourne, 1972; Efron, 1970; Haber & Standing, 1970). In any case, before concluding that there is no age-related change in icon duration it is important to obtain converging evidence from another paradigm.

EXPERIMENT 2

A second study was designed to determine the duration of the icon in subjects of different ages using a direct measure. The threshold of continuity procedure of Haber and Standing (1969) was modified, because it was expected that it might be difficult for children to judge whether an intermittent stimulus is "both whole and continuous." Indeed, it would be difficult to explain and demonstrate the concept of continuity. Therefore, a small disc of light was presented on a black background and, after a delay of darkness, was followed by a second identical disc of light. It was reasoned that the dark interval would not be detected when the ISI was shorter than the duration of the icon of the first stimulus.

The threshold was the interval at which the subject reported "black" 50% of the time. In order to help subjects adopt a stable criterion of "blackness," the instructions encouraged them to match the level of brightness of the dark interval with the black adaptation field. This strategy was useful in discouraging subjects from reporting "black" when the apparent brightness of the first stimulus just decreased discriminably, as is thought to occur in studies of TFT (e.g., Kietzman & Sutton, 1968). The threshold was measured at two stimulus durations, 70 and 25 msec, which correspond to the mean stimulus durations of the 5-year-olds and older subjects in Experiment 1.

Several changes were made in the procedures of previous direct measures of the development of icon duration (e.g., the TFT studies). In previous studies, the Method of Limits was used to determine the threshold.

The use of the Method of Limits in developmental research has been criticized (see Gerjuoy & Winters, 1969; Wohlwill, 1960). Instead, the Method of Constant Stimuli was used to present the ISIs randomly. In the previous studies, little or no practice was given before the test trials were conducted. In the present study, two practice sessions preceded the test sessions. In the practice sessions, the subjects were able to learn the task, and a range of five ISIs was selected for each subject individually. A third change in the present study was a considerable increase in the number of trials. In previous TFT studies (e.g., Pollack et al., 1968, 1969; Thor, 1970) no more than five ascending and descending trials were used. In the present study a total of 40 trials were given at each ISI.

Method

Subjects

The subjects were unpaid volunteers from undergraduate classes at Dalhousie University, from grade three at Le Marchant and Sir Charles Tupper Schools, all in Halifax, N. S., and from the primary (kindergarten) class at Le Marchant School. In each age group there were three males and one female. The mean ages were: 21.4 years for the adults; 8.9 years for the third-graders; and 5.8 years for the primary students. Children with behavioural problems, as determined by their school principals, were not tested. All subjects were screened for binocular distance acuity of 20/29 or better, with a Bausch and Lomb Modified Orthorater.

Apparatus

A Scientific Prototype (Model GB) three-field tachistoscope was used for stimulus presentation. In addition, the sequence of stimulus presentations was controlled by means of BRS solid-state logic interfaced with the tachistoscope. ISIs were quickly and quietly varied from trial to trial by adjusting a potentiometer, which set the desired interval on a solid-state timer, and the calibrated intervals were displayed on a digital read-out. The tachistoscope was triggered by the experimenter when he pressed a hand-held button, which activated a microswitch.

The stimulus was a circle of light in the centre of a flat black sheet of metal which was backlighted in Field 1 of the tachistoscope. The light passed through a circular opening 22' in diameter, and a blank white index card was placed on the opposite side of the light source. The luminance of the stimulus was 34.3 cd/m^2, as measured with an SEI photometer. In the centre of the flat black fixation field, four tiny holes 2' 4" in diameter, were situated at the corners of an imaginary square, 44' to the side. The adaptation field was backlighted, with a flat black field behind the lights. The luminance of the fixation points was .86 cd/m^2 and was identical to the ambient level of illumination in the testing room.

Procedure

Subjects were individually tested in a dimly-lit room. At the beginning of each session, the subject was allowed to become accustomed to the illumination for 5 min. In the first session, the children were told that they were going to play a game. The subject was asked to look into the tachistoscope at the fixation field and to report what he saw.

Then he was asked to report the colour in the middle of the four dots, i.e., black. The stimulus field, an illuminated circle on a black background, was then turned on and the colour in the middle of the dots was again requested, i.e., white. This procedure was repeated several times, until it was clear that the subject was attending to the middle of the fixation field and could correctly identify its colour. At that point, the circle was presented twice, for 26 or 70 msec (counterbalanced across subjects) with an ISI of 500 msec, and the subject was asked how many circles he saw. Then he was asked to look again and to report whether it was black or white in the middle of the four dots "after the first circle and before the second circle."[4] This procedure was repeated several times until it was clear that the instructions were understood. The ISI was then set at 100 msec and the same question was asked. If the subject reported "black," he was told that it was black after both circles appeared, but was white (or at least not black) after the first circle and before the second circle. It was emphasized that the subject was to report "black" only if the middle of the field was "dark black," like the fixation field. This instruction was intended to bias subjects against reporting "black" unless they were certain. If it was white, whitish, or grey, i.e., any colour other than dark black, the appropriate response was "white."[5] The subject was then given several practice trials at relatively

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[4] In pilot study, the 5-year-old subjects found the task difficult when they were asked to report the colour "between the two circles." This instruction was misinterpreted as spatially in the middle of the circles, i.e., in the middle of the fixation dots, and therefore white, when the two stimuli came on.

[5] In the pilot study, subjects were asked to respond "yes" or "no" if the area was seen as black or "nonblack," respectively. However, it was unclear what the youngest subjects were responding "yes" to. By requiring

[redacted]

high and low ISIs presented at random, until performance was perfect.[6]

There were two practice sessions of 100 trials each.[7] The two stimulus durations, 25 and 70 msec, correspond to the mean stimulus durations at which the older subjects and the 5-year-olds achieved criterion performance in the partial-report study. The stimulus durations were counterbalanced over sessions and subjects.

In the practice sessions, a range of ISIs was selected, such that at the lowest value, the subject could always respond "white" and at the highest ISI, "black." To locate the end-points of the range, a modified convergence method was used: on each block of 9 to 15 trials, there was one high, middle, and low ISI, e.g., 500, 350, and 100 msec, respectively, presented in three-trial blocks. As long as the subject reliably responded "black" for the high ISI and "white" for the low ISI, these values were decreased and increased, respectively, by 25 to 50 msec. For one-half of the subjects, the middle ISI was increased on the second block of trials by 25 to 50 msec. On the third block, it was decreased

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them to name the colours explicitly, they would be reminded exactly what they were required to do. While saying "white" to nonblack stimuli might not be ideal, it was expected that "nonblack" would be incomprehensible for the youngest children. One 5-year-old occasionally reported: "It was really grey, but you told me to call that 'white,'" suggesting that he understood the instructions.

[6]Two 5-year-old subjects and one 8-year-old subject did not understand the instructions. Of these, two subjects responded "black" and "white" approximately equally at all ISIs; they were dropped from the study after three practice sessions, and the third subject was replaced after the first session.

[7]The only exceptions were the following: two 5-year-olds were tired after 75 trials of Session 1, and testing ceased for that session. Also, one 5-year-old required a third practice session for stable performance.

[redacted]

from its initial duration. On subsequent blocks, the middle ISI was alternately increased or decreased from its duration two blocks before. For the remaining subjects, the procedure was identical, except the changes in the duration of the middle ISI were in the opposite direction. This procedure served to prevent response bias and to converge on the final range of ISIs relatively quickly. Feedback was occasionally given on the high and low ISIs, to maintain motivation in the children.

By the end of the practice sessions, five ISIs were chosen for each of the two stimulus durations, and only those values were used in the test sessions. The highest ISI was slightly longer than the interval at which the subject began to report "black" less than 100% of the time, and the lowest ISI was slightly shorter than the interval at which the frequency of "black" responses began to exceed 0%. The intermediate three ISIs were equally spaced within that range.

There were four test sessions of 100 trials each, with a 5-min rest after each 25-trial block. Within each block, the ISIs were randomly presented in blocks of five trials. Over the four sessions, there were 40 trials per ISI, at each stimulus duration. The two stimulus durations were counterbalanced within and between sessions, and across subjects. There were four different sequences of trials, and the four subjects in each of the three age groups were tested with a unique sequence. No feedback was given in any of the test trials. At the end of each session, the children were given a small prize for good behaviour.

Results

The percentage of "black" responses was calculated for each ISI over the four test sessions, separately for each subject and at each stimulus duration. The percentages were transformed into probits[8] (see Finney, 1971) and the Method of Least Squares was used to fit a straight line to the distribution of probits over ISIs[9] (see Figure 3).

There was a great deal of variability among the thresholds of the three age groups at each stimulus duration (see Table 9). The variability may be due to individual differences in the selection of a criterion of "blackness.". Nevertheless, the threshold of each subject appeared to be fairly stable in the test sessions.

A 3(age) x 2(stimulus duration) analysis of variance was calculated on the thresholds and it was found that the estimate of icon duration was significantly longer for the 25-msec stimulus than for the 70-msec stimulus, F (1, 9) = 24.67, $p < .01$ (Table 10). The mean thresholds were 305.1 and 262.1 msec, respectively. Neither the main effect of age nor the interaction between age and stimulus duration were found to be statistically significant.

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[8]The writer is indebted to Dr. M. Regan for suggesting this analysis. With the probit analysis, not only the ISI above and below the 50% point are used to interpolate the threshold interval; up to five ISIs may be used (there are no tabled probits for 0% and 100%). Therefore, this measure is more precise than that based on the two percentages about 50%. Probit analysis transforms the ogive obtained with the Method of Constant Stimuli into a straight line, with the threshold corresponding to the probit of 5.0 on the regression line. In order to ensure that the pattern of results was not different with probits and percentages, the statistical analysis was repeated with the percentages, and the conclusions were identical.

[9]The coefficient of determination (r^2) was greater than .90 for 22 of the 24 regression lines, with a mean value of .95. In other words, the lines provided an excellent fit to the data.

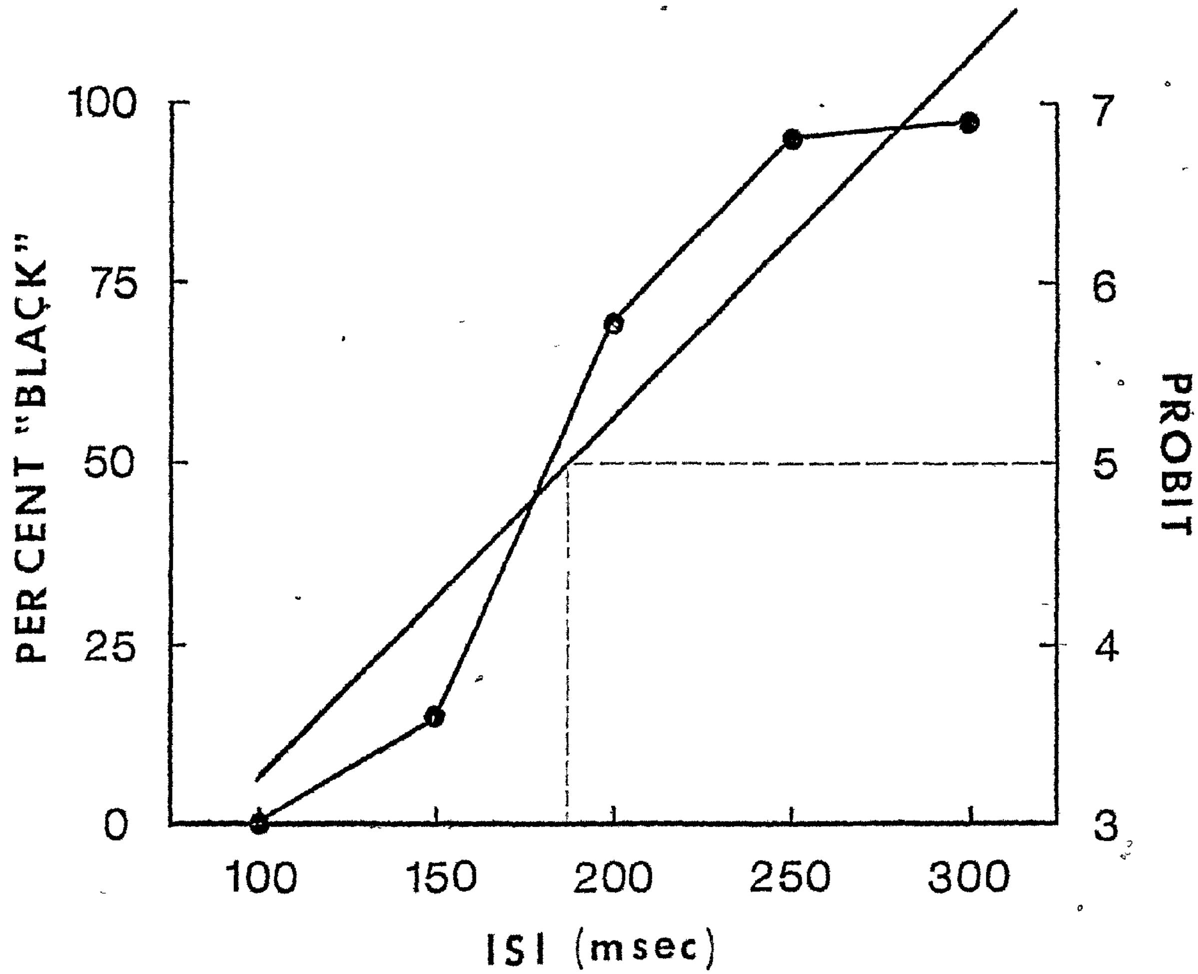

Figure 3. Example of the transformation of per cent "black" report ● to a straight line (Y = .02X + 1.23) when using probits. The threshold is shown as the ISI corresponding to a probit of 5. The data are taken from the 25-msec stimulus duration of a 5-year-old: Experiment 2.

Table 9

Summary of Individual Subjects' Thresholds at Each Stimulus

Duration: Experiment 2

Age (years)	Subject	25	70
5	1	186.88	168.92
	2	353.02	319.05
	3	229.89	167.24
	4	526.72	407.06
$\overline{X}$		324.13	265.57
9	1	270.72	214.11
	2	346.46	333.30
	3	196.64	171.50
	4	303.07	235.90
$\overline{X}$		279.22	238.70
21	1	197.41	160.87
	2	234.24	212.88
	3	290.53	264.43
	4	525.09	490.17
$\overline{X}$		311.82	282.09
Grand $\overline{X}$		305.06	262.12

Table 10

Analysis of Variance on Probit-Deprived Thresholds:

Experiment 2

Between Subjects	11	268,978.27		
Age (A)	2	7,351.13	3,675.56	0.13
$Error_B$	9	261,627.14	29,069.68	
Within Subjects	12	15,966.90		
Stimulus Durations (SD)	1	11,118.06	11,118.06	24.67 *
A x SD	2	791.97	395.99	0.88
$Error_W$	9	4,056.86	450.76	
Total	23	284,945.17		

* $p < .01$

Discussion

There was no difference in threshold among the three age groups, at either stimulus duration. However, the 25-msec stimulus appeared to persist for a longer period after stimulus offset than the 70-msec stimulus. The inverse relationship between apparent and actual stimulus durations is consistent with the results of other direct measures of icon duration (Briggs & Kinsbourne, 1972; Efron, 1970: Haber & Standing, 1970).

In studies of two-pulse temporal discrimination, it has been found that the data are more systematic across experiments when described as a function of the interval between stimulus onsets, i.e., stimulus onset asynchrony (SOA), rather than the interval between stimulus offsets, i.e., ISI (Boynton, 1972). Therefore, the threshold ISI of each subject was transformed into SOA, by adding the stimulus duration to the ISI. The mean SOAs for the 25- and 70-msec stimuli were 330.1 and 332.1 msec, respectively (see Figure 4). A 3(age) x 2(stimulus duration) analysis of variance revealed that neither of the main effects nor their interaction was statistically significant. It appears that the phenomenal stimulus duration is approximately 330 msec from stimulus onset, independent of the actual stimulus duration, for subjects of all three age groups.

The magnitude of the thresholds obtained in the present study is quite similar to many of the direct measures of icon duration (see Table 1). In particular, the present estimates of icon duration are considerably larger than the TFT, for all age groups.

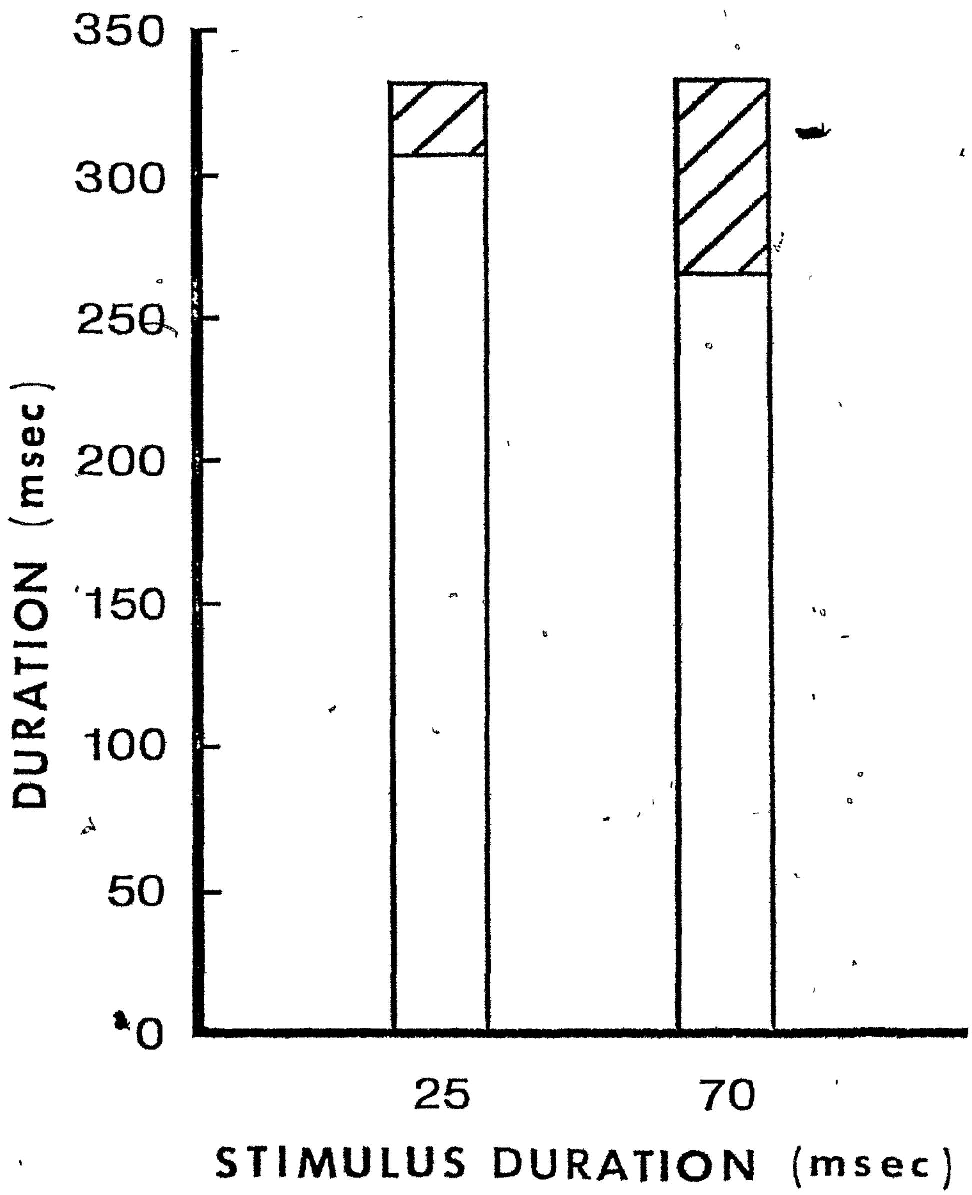

Figure 4. Mean phenomenal stimulus duration as a function of actual stimulus duration. White bars represent threshold ISI; striped bars are the stimulus duration; total height of the bars is the sum of stimulus duration and ISI, i.e., SOA. Experiment 2.

GENERAL DISCUSSION

In contrast to the earlier developmental studies of TFT and partial report, in the present study neither the direct measure nor the indirect measure suggest any age-related change in the duration of the icon. The failure to reject a null hypothesis is often considered uninformative because of the possibility that factors such as sampling error may have prevented a "true difference" from emerging. In the present research, considerable care was taken to control for extraneous variables and much more data was obtained than in the previously-cited developmental studies. Furthermore, the fact that identical results occurred in both experiments, each using a different measure, provides converging evidence for the view that the duration of the icon does not change over the range of ages tested.

Nevertheless, a paradox arises when the results of the two studies are compared. In the partial-report study, the 5-year-olds required a stimulus duration of about 70 msec in order to achieve criterion, while older children and adults only required stimulus exposures of about 25 msec. The finding that young children require a longer stimulus duration for equal performance with older subjects is not limited to the partial-report paradigm. For example, this result has been reported in studies of stimulus identification (e.g., Blake, 1974; Haith, Morrison, & Sheingold, 1970; Munsinger, 1965) and of detection of the orientation of a form (e.g., Ghent, 1960; Ghent & Bernstein, 1961; Schaller & Dziadosz, 1976). In the second study, the duration of the icon was shorter with the 70-msec stimulus than with the 25-msec stimulus, for subjects of all three age groups. If it is assumed that the duration of the icon in the partial-report study was inversely related to stimulus duration, then it would appear that the 5-year-olds achieved criterion with a <u>shorter</u> icon. An explanation of the effects of longer stimulus durations in the partial-report and other tasks might involve some aspect of processing other than the duration of the icon.

One developmental difference in information processing is that younger children require more complete and clearer information for stimulus identification. For example, a stimulus must be more sharply focused (Potter, 1966; Mackworth & Bruner, 1970) and more redundant (Westcott & Tolchin, 1968; Wohlwill, 1960) for younger children than older subjects. In addition, younger children are less accurate than older children in identifying incomplete line drawings or photographs (Goldstein & Mackenberg, 1966; Gollin, 1965; Spitz & Borland, 1971).

The young child's need for both a longer and clearer stimulus to achieve performance equal to that of adults may be related in the following manner. In adults ratings of stimulus clarity, defined as the sharpness or blackness of the contours, have been found to increase with stimulus duration (Dick, 1974; Haber & Standing, 1968; Weintraub & McNulty, 1973). If it is assumed that stimulus clarity also improves with stimulus duration in children, then the apparent paradox in the partial-report study may be resolved. Only at the longer duration would the stimulus have been sufficiently clear for the young children to reach criterion.

An alternative explanation for the effect of the longer stimulus duration in the partial-report study is suggested by developmental studies of visual backward masking. In young children a masking stimulus interferes with recognition of a previously-presented test stimulus for a longer interval after the test stimulus than it does in older children and adults (Liss & Haith, 1970; Pollack, 1965; Spitz & Thor, 1968; Welsandt, Zupnick, & Meyer, 1973). On the basis of this finding it has been suggested that the rate of information processing is slower in young children (e.g., Spitz & Thor, 1968).[10] In the present partial-report study, it is possible that the 5-year-olds required a longer period of time than the older subjects to process the information in the stimulus array. Once the additional processing time was provided, the accuracy of partial report in the 5-year-olds declined at the same rate over ISIs as in older subjects.

One problem with the second explanation is that the term "processing" is too vague. Does processing refer to the formation of the icon, retrieval of information from the icon, or perhaps encoding from the icon into more permanent storage? A challenge for future research in information processing is to devise operational definitions and converging operations for the different hypothesized stages of processing from iconic storage. Averbach & Coriell (1961) did attempt to separate two components of retrieval or readout from the icon: selective readout, which is directed by the cue, and nonselective readout, which is independent of the cue.

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[10] In all of those masking studies, the stimulus duration was identical for all age groups. There appeared to be a ceiling effect on the performance of the older subjects or, in some cases, of all age groups, in the no-mask condition. The critique that a confounding of the age by delay of mask interaction exists in the partial-report studies applies to these studies as well. In one study (Blake, 1974), there was no difference in masking between 4-year-olds and older subjects. Blake presented the stimulus for 30 msec to the 4-year-olds and for 15 msec to the 8-year-olds and adults; however, performance was virtually correct in all three age groups at the longest delay (250 msec) suggesting that a ceiling effect was not eliminated. Until a masking study is conducted at subceiling levels, the hypothesized age-related changes in the rate of information processing cannot be considered conclusive.

Other researchers have ignored the distinction, possibly because the measures were derived in a complex manner.

Implications of the Present Research

In the present research, it has been concluded that the duration of the icon does not change over the age range from about 5 to 23 years. It would be interesting to determine whether this result can be generalized to younger age groups as well. Unfortunately, many problems might be encountered in attempts to use the present direct and indirect procedures with children under 5 years of age, including possible difficulties in explaining the instructions and maintaining their motivation and attention long enough to obtain sufficient data. A tentative solution to this problem might be to adopt psychophysiological procedures such as visual evoked potentials, which have been correlated with the phenomenon of visual masking in adults (e.g., Donchin & Lindsley, 1965; Schiller & Chorover, 1966). Such a technique might be applied successfully both to very young children and also to other subject populations, such as mentally retarded children.

There have been some attempts to compare partial-report performance in retarded and nonretarded subjects (e.g., Libkuman & Friedrich, 1972; Pennington & Luszcz, 1975); however, many of the criticisms of the methodology of the previously-cited developmental studies using the partial-report procedure apply to these studies as well. The present research has demonstrated that the design and procedure of such research must be improved in order to provide interpretable results.

It has been suggested (e.g., Stanley & Hall, 1973) that the duration of the icon and reading ability might be related. However, their relationship has been inconsistent when different measures of icon duration have been used. On the one hand, Stanley and Hall (1973) have claimed that the icon lasts longer in dyslexics than in normal readers, using a stimulus integration procedure (Eriksen & Collins, 1967). On the other hand, Stanley and Molloy (1975) have reported that there was no difference in icon duration between dyslexics and normal readers when they used a threshold of continuity procedure (Haber & Standing, 1969). It was suggested in the Introduction that stimulus integration studies might not be measuring the duration of the icon per se. Future research using the procedures of the present study might resolve the discrepancy between results. If the duration of the icon is found to be the same in dyslexics and normal readers, remedial procedures might be directed toward other stages of information processing, such as short-term storage.

Young children perform more poorly than older subjects when they are required to report more than one item from a multi-item array. This result has been obtained in studies of whole report (Haith, Morrison, Sheingold, & Mindes, 1970), partial-report (Dick & Loader, 1974), and visual backward masking (Blake, 1974). Given the results of the present research, this developmental trend is probably not due to an age-related change in the duration of the icon. Rather, an explanation might be sought at other stages of information processing. For example, Dick (1974) has suggested that "the single-item cueing procedure reflects aspects of iconic memory but...multiple-item cueing reflects short-term memory" (p. 583) in the partial-report procedure. Since it has been shown that the capacity of short-term storage increases with age (e.g., Huttenlocher & Burke, 1976; Jablonski, 1974), one would expect younger children to have greater difficulty in reporting more than one item on each trial. For this reason, in the present partial-report experiment only a single item was cued on every trial.

Current Status of Iconic Storage

Since Sperling's (1960) seminal research, the concept of iconic storage has been widely accepted as one of the earliest stages of information processing (e.g., Atkinson & Shiffrin, 1968; Haber, 1973; Neisser, 1967). A variety of different techniques have since been devised to measure the duration of the icon and, as was pointed out earlier, the results of the different measures have not always been consistent. One problem for future research in information processing is to provide a clear definition of the icon along with unambiguous procedures to measure its characteristics.

Recently, several critiques of iconic storage have appeared in the experimental literature. Holding (e.g., 1975) has questioned the very existence of iconic storage. He has attempted to demonstrate that the superiority of partial-report over whole report can be explained by other means, such as guessing strategies and output interference. An account of Holding's arguments are beyond the scope of the present discussion. Suffice it to say that a number of investigators have presented convincing counterarguments (e.g., Coltheart, 1975; Coltheart, Lea, & Thompson, 1974; Dick, 1971, 1974; von Wright, 1972). It does not appear that the concept of the icon has been laid to rest.

Sakitt (1975, 1976) has recently argued that the locus of iconic storage is in the rods of the retina.[11] If the icon is a basic sensory phenomenon as Sakitt has suggested, then the present finding of no age-related changes in the duration of the icon is perhaps less surprising than if the icon were a "higher-order" cognitive phenomenon which might be expected to develop with age. Future research will determine if Sakitt's hypothesis is correct.

Conclusions

The present research has demonstrated that the duration of the icon does not change with age. Although previous developmental studies have suggested such a change, the methodology of those studies is subject to numerous criticisms.

The paradox between the present experiments has not been resolved. The results of the second study suggest that the duration of the icon is identical for all three age groups; however, the icon was shorter at the longer stimulus duration. In the partial-report study, the stimulus duration was longer for the 5-year-olds, suggesting that the icon may have been shorter, even though they achieved equal partial-report performance. Future research may resolve this paradox.

It was suggested that the improved procedures of the present research be used to examine iconic storage in children under 5 years of age, in

[11] However, there are other data suggesting that processing of iconic storage is central rather than peripheral. For example, the estimates of icon duration obtained with direct measures are identical for monocular and dichoptic presentations (e.g., Briggs & Kinsbourne, 1972; Haber & Standing, 1969).

mentally retarded children, and in dyslexics. Finally, future research might be directed toward other sources of developmental differences, such as short-term storage.

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