Sperling, G. (1960). The information available in brief visual presentations.
Psychological Monographs: General and Applied, 74(11, Whole No. 498). Pp. 1-29.

Vol. 74, No. 11 Whole No. 498, 1960

Psychological Monographs: General and Applied

THE INFORMATION AVAILABLE IN BRIEF VISUAL PRESENTATIONS[1]

GEORGE SPERLING[2]

Harvard University

How much can be seen in a single brief exposure? This is an important problem because our normal mode of seeing greatly resembles a sequence of brief exposures. Erdmann and Dodge (1898) showed that in reading, for example, the eye assimilates information only in the brief pauses between its quick saccadic movements. The problem of what can be seen in one brief exposure, however, remains unsolved. The difficulty is that the simple expedient of instructing the observer of a single brief exposure to report what he has just seen is inadequate. When complex stimuli consisting of a number of letters are tachistoscopically presented, observers enigmatically insist that they have seen more than they can remember afterwards, that is, report afterwards.[3] The apparently simple question: "What did you see?" requires the observer to report both what he remembers and what he has forgotten.

The statement that *more is seen than can be remembered* implies two things. First, it implies a memory limit, that is, a limit on the (memory) report. Such a limit on the number of items which can be given in the report following any brief stimulation has, in fact, been generally observed; it is called the span of attention, apprehension, or immediate-memory (cf. Miller, 1956b). Second, *to see more than is remembered* implies that more information is available during, and perhaps for a short time after, the stimulus than can be reported. The considerations about available information are quite similar, whether the information is available for an hour (as it is in a book that is borrowed for an hour), or whether the information is available for only a fraction of a second (as in a stimulus which is exposed for only a fraction of a second). In either case it is quite probable that for a limited period of time more information will be available than can be reported. It is also true that initially, in both examples, the information is available to vision.

In order to circumvent the memory limitation in determining the information that becomes available following a brief exposure, it is obvious that the observer must not be required to give a report which exceeds his memory span. If the number of letters in the stimulus exceeds his memory span, then he cannot give a whole report of all the letters. Therefore, the observer must be required to give only a partial report of the stimulus contents. Partial reporting of available information is, of course, just what is required by ordinary schoolroom examinations and by other methods of sampling available information.

An examiner can determine, even in a short test, approximately how much the

---

[1] This paper is a condensation of a doctoral thesis (Sperling, 1959). For further details, especially on methodology, and for individual data, the reader is referred to the original thesis. It is a pleasure to acknowledge my gratitude to George A. Miller and Roger N. Shepard whose support made this research possible and to E. B. Newman, J. Schwartzbaum and S. S. Stevens for their many helpful suggestions. Thanks are also due to Jerome S. Bruner for the use of his laboratory and his tachistoscope during his absence in the summer of 1957. This research was carried out under Contract AF 33(038)-14343 between Harvard University and the Operational Applications Laboratory, Air Force Cambridge Research Center, Air Research Development Command.

[2] Now at Bell Telephone Laboratories, Murray Hill, New Jersey.

[3] Some representative examples are: Bridgin (1933), Cattell (1883), Chapman (1930), Dallenbach (1920), Erdmann and Dodge (1898), Glanville and Dallenbach (1929), Külpe (1904), Schumann (1922), Wagner (1918), Whipple (1914), Wilcocks (1925), Woodworth (1938).

student knows. The length of the test is not so important as that the student not be told the test questions too far in advance. Similarly, an observer may be "tested" on what he has seen in a brief exposure of a complex visual stimulus. Such a test requires only a partial report. The specific instruction which indicates which part of the stimulus is to be reported is then given only after termination of the stimulus. On each trial the instruction, which calls for a specified part of the stimulus, is randomly chosen from a set of possible instructions which cover the whole stimulus. By repeating the interrogation (sampling) procedure many times, many different random samples can be obtained of an observer's performance on each of the various parts of the stimulus. The data obtained thereby make feasible the estimate of the total information that was available to the observer from which to draw his report on the average trial.

The time at which the instruction is given determines the time at which available information is sampled. By suitable coding, the instruction may be given at any time: before, during, or after the stimulus presentation. Not only the available information immediately following the termination of the stimulus, but a continuous function relating the amount of information available to the time of instruction may be obtained by such a procedure.

Many studies have been conducted in which observers were required to give partial reports, that is, to report only on one aspect or one location of the stimulus. In prior experiments, however, the instructions were often not randomly chosen, and the set of possible instructions did not systematically cover the stimulus. The notions of testing or sampling were not applied.[4] It is not surprising, therefore, that estimates have not been made of the total information available to the observer following a brief exposure of a complex stimulus. Furthermore, instructions have generally not been coded in such a way as to make it possible to control the precise time at which they were presented. Consequently, the temporal course of available information could not have been quantitatively studied. In the absence of precise data, experimenters have all too frequently assumed that the time for which information is available to the observer corresponds exactly to the physical stimulus duration. Wundt (1899) understood this problem and convincingly argued that, for extremely short stimulus durations, the assumption that stimulus duration corresponded to the duration for which stimulus information was available was blatantly false, but he made no measurements of available information.

The following experiments were conducted to study quantitatively the information that becomes available to an observer following a brief exposure. Lettered stimuli were chosen because these contain a relatively large amount of information per item and because these are the kind of stimuli that have been used by most previous investigators. The first two experiments are essentially control experiments; they attempt to confirm that immediate-memory for letters is independent of the parameters of stimulation, that it is an individual characteristic. In the third experiment the number of letters available immediately after the extinction of the stimulus is determined by means of the sampling (partial report) procedure described above. The fourth experiment explores decay of available information with time. The fifth experiment examines some exposure parameters. In the sixth experiment a technique which fails to demonstrate a large amount of available information is investigated. The seventh experiment deals with the role of the historically important variable: order of report.

[4] The experiments referred to are (cf. Sperling, 1959): Külpe (1904), Wilcocks (1925), Chapman (1932), Long, Henneman, and Reid (1953), Long and Lee (1953a), Long and Lee (1953b), Long, Reid, and Garvey (1954), Lawrence and Coles (1954), Adams (1955), Lawrence and Laberge (1956), Broadbent (1957a).

General Method

Apparatus. The experiments utilized a Gerbrands tachistoscope.[5] This is a two-field, mirror tachistoscope (Dodge, 1907b), with a mechanical timer. Viewing is binocular, at a distance of about 24 inches. Throughout the experiment, a dimly illuminated fixation field was always present.

The light source in the Gerbrands tachistoscope is a 4-watt fluorescent (daylight) bulb. Two such lamps operated in parallel light each field. The operation of the lamps is controlled by the microswitches, the steady-state light output of the lamp being directly proportional to the current. However, the phosphors used in coating the lamp continue to emit light for some time after the cessation of the current. This afterglow in the lamp follows an exponential decay function consisting of two parts: the first, a blue component, which accounts for about 40% of the energy, decays with a time constant which is a small fraction of a millisecond; the decay constant of the second, yellow, component was about 15 msec. in the lamp tested. Fig. 1 illustrates a 50-msec. light impulse on a linear intensity scale. The exposure time of 50 msec. was used in all experiments unless exposure time was itself a parameter. Preliminary experiments indicated that, with the presentations used, exposure duration was an unimportant parameter. Fifty msec. was sufficiently short so that eye movements during the exposure were rare, and it could conveniently be set with accuracy.

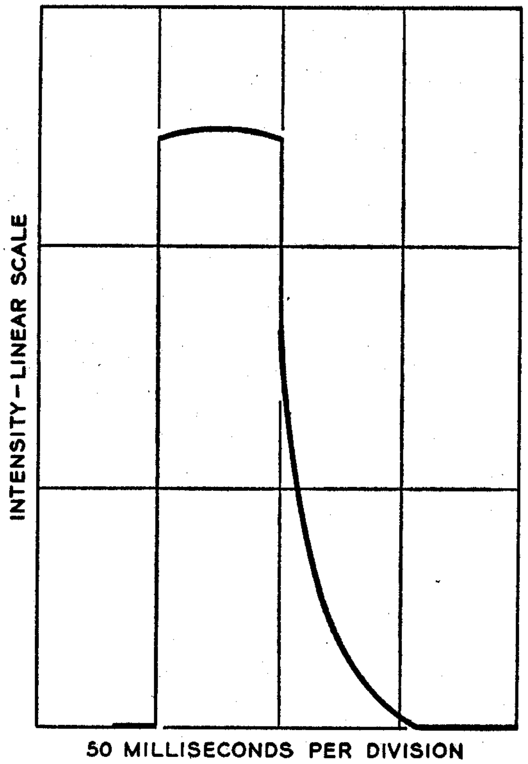

Fig. 1. A 50-millisecond light flash, such as was used in most of the experiments. (Redrawn from a photograph of an oscilloscope trace)

Stimulus materials. The stimuli used in this experiment were lettered 5x8 cards viewed at a distance of 22 inches. The lettering was done with a Leroy No. 5 pen, producing capital letters about 0.45 inch high. Only the 21 consonants were used, to minimize the possibility of *S*s interpreting the arrays as words. In a few sets of cards the letter Y was also omitted. In all, over 500 different stimulus cards were used.

There was very little learning of the stimulus materials either by the *S*s or by the *E*. The only learning that was readily apparent was on several stimuli that had especially striking letter combinations. Except for the stimuli used for training, no *S* ever was required to report the same part of any stimulus more than two or three times, and never in the same session.

Figure 2 illustrates some typical arrays of letters. These arrays may be divided into several categories: (*a*) stimuli with 3, 4, 5, 6, or 7 letters normally spaced on a single line; (*b*) stimuli with six letters closely spaced on a single line (6-massed); (*c*) stimuli having two rows of letters with three letters in each row (3/3), or two rows

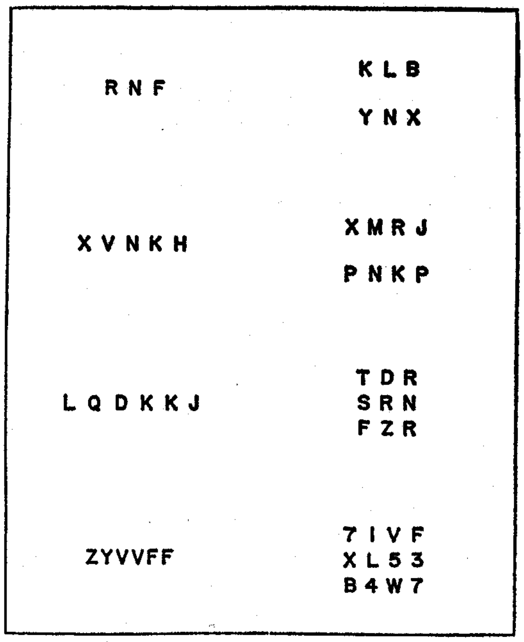

Fig. 2. Typical stimulus materials. Col. 1: 3, 5, 6, 6-massed. Col. 2: 3/3, 4/4, 3/3/3, 4/4/4 L&N.

[5] Ralph Gerbrands Company, 96 Ronald Road, Arlington 74, Massachusetts.

of four letters each (4/4); (*d*) stimuli having three rows of letters with three letters in each row (3/3/3). The stimulus information, calculated in bits, for some of the more complex stimuli is 26.4 bits (6-letters, 6-massed, 3/3), 35.1 bits (4/4), and 39.5 bits (3/3/3).

In addition to stimuli that contained only letters, some stimuli that contained both letters and numbers were used. These had eight (4/4 L&N, 35.7 bits) and twelve symbols (4/4/4 L&N, 53.6 bits), respectively, four in each row. Each row had two letters and two numbers—the positions being randomly chosen. The *S* was always given a sample stimulus before L&N stimuli were used and told of the constraint above. He was also told that O when it occurred was the number "zero" and was not considered a letter. Calculated with these constraints, the information in each row of four letters and numbers (17.9 bits) on such a card is nearly equal to the information in a row of four randomly chosen consonants (17.6 bits), even though there are different kinds of alternatives in each case.

Subjects. The nature of the experiments made it more economical to use small numbers of trained *S*s rather than several large groups of untrained *S*s. Four of the five *S*s in the experiment were obtained through the student employment service. The fifth *S* (RNS) was a member of the faculty who was interested in the research. Twelve sessions were regularly scheduled for each *S*, three times weekly.

Instructions and trial procedures. *S* was instructed to look at the fixation cross until it was clearly in focus; then he pressed a button which initiated the presentation after a 0.5-sec. delay. This procedure constituted an approximate behavioral criterion of the degree of dark adaptation prior to the exposure, namely, the ability to focus on the dimly illuminated fixation cross.

Responses were recorded on a specially prepared response grid. A response grid appropriate to each stimulus was supplied. The response grid was placed on the table immediately below the tachistoscope, the room illumination being sufficient to write by. The *S*s were instructed to fill in all the required squares on the response grid and to guess when they were not certain. The *S*s were not permitted to fill in consecutive X's, but were required to guess "different letters." After a response, *S* slid the paper forward under a cover which covered his last response, leaving the next part of the response grid fully in view.

Series of 5 to 20 trials were grouped together without a change in conditions. Whenever conditions or stimulus types were changed, *S* was given two or three sample presentations with the new conditions or stimuli. Within a sequence of trials, *S* set his own rate of responding. The *S*s (except ND) preferred rapid rates. In some conditions, the limiting rate was set by the *E*'s limitations in changing stimuli and instruction tones. This was about three to four stimuli per minute.

Each of the first four and last two sessions began with and/or ended with a simple task: the reporting of all the letters in stimuli of 3, 4, 5, and 6 letters. This procedure was undertaken in addition to the usual runs with these stimuli to determine if there were appreciable learning effects in these tasks during the course of the experiment and if there was an accuracy decrement (fatigue) within individual sessions. Very little improvement was noted after the second session. This observation agrees with previous reports (Whipple, 1914). There was little difference between the beginning and end of sessions.

Scoring and tabulation of results. Every report of all *S*s was scored both for total number of letters in the report which agreed with letters in the stimulus and for the number of letters reported in their correct positions. Since none of the procedures of the experiments had an effect on either of these scores independently of the other, only the second of these, ***letters in the correct position,*** is tabulated in the results. This score, which takes position into account, is less subject to guessing error,[6] and in some cases it is more readily interpreted than a score which does not take position into account. As the maximum correction for guessing would be about 0.4 letter for the 4/4/4 (12-letter) material—and considerably less for all other materials—no such correction is made in the treatment of the data. In general, data were not tabulated more accurately than 0.1 letter.

Data from the first and second sessions were not used if they fell below an *S*'s average performance on these tasks in subsequent sessions. This occurred for reports of five and of eight (4/4) letters for some *S*s. A similar criterion applied in later sessions for tasks that were initiated later. In this case, the results of the first "training" session(s) are not incorporated in the total tabulation if they lie more than 0.5 letter from *S*'s average in subsequent sessions.

Experiment 1: Immediate-Memory

When an *S* is required to give a complete (whole) report of all the letters on a briefly exposed stimulus, he will generally not re-

[6] If there are a large number of letters in the stimulus, the probability that these same letters will appear somewhere on the response grid, irrespective of position, becomes very high whether or not *S* has much information about the stimulus. In the limit, the correspondence approaches 100% provided only that the relative frequency of each letter in the response matches its relative frequency of occurrence in the stimulus pack. If the response is scored for both letter ***and*** position, then the percent guessing correction is independent of changes in stimulus size.

port all the letters correctly. The average number of letters which he does report correctly is usually called his *immediate-memory span* or *span of apprehension for that particular stimulus material under the stated observation conditions.* An expression such as immediate-memory span (Miller, 1956a) implies that the number of items reported by *S* remains invariant with changes in stimulating conditions. The present experiment seeks to determine to what extent the span of immediate-memory is independent of the number and spatial arrangement of letters, and of letters and numbers on stimulus cards. If this independence is demonstrated, then the qualification "for that particular stimulus material" may be dropped from the term immediate-memory span when it is used in these experiments.

Procedure. *S*s were instructed to write all the letters in the stimulus, guessing when they were not certain. All 12 types of stimulus materials were used. At least 15 trials were conducted with each kind of stimulus with each *S*. Each *S* was given at least 50 trials with the 3/3 (6-letter) stimuli which had yielded the highest memory span in preliminary experiments. The final run made with any kind of stimulus was always a test of immediate-memory. This procedure insured that *S*s were tested for memory when they were maximally experienced with a stimulus.

Results. The lower curves in Fig. 3 represent the average number of letters correctly reported by each *S* for each material.[7] The most striking result is that immediate-memory is constant for each *S*, being nearly independent of the kind of stimulus used. The immediate-memory span for individual *S*s ranges from approximately 3.8 for JC to approximately 5.2 for NJ with an average immediate-memory span for all *S*s of about 4.3 letters. (The upper curves are discussed later.)

The constancy which is characteristic of individual immediate-memory curves of Fig. 3 also appears in the average curve for all *S*s. For example, three kinds of stimuli were used that had six letters each: six letters normally spaced on one line, 6-massed, and 3/3-letters (see Fig. 2). When the data for all *S*s are pooled, the scores for each of these three types of materials are practically the same: the range is 4.1–4.3 letters. The same constancy holds for stimuli containing eight symbols. The average number of letters correctly reported for each of the two different kinds of eight letter stimuli, 4/4, 4/4 L&N, is nearly the same: 4.4, 4.3, respectively.

Most *S*s felt that stimuli containing both letters and numbers were more difficult than those containing letters only. Nevertheless, only NJ showed an objective deficit for the mixed material.

In conclusion, the average number of correct letters contained in an *S*'s whole report of the stimulus is approximately

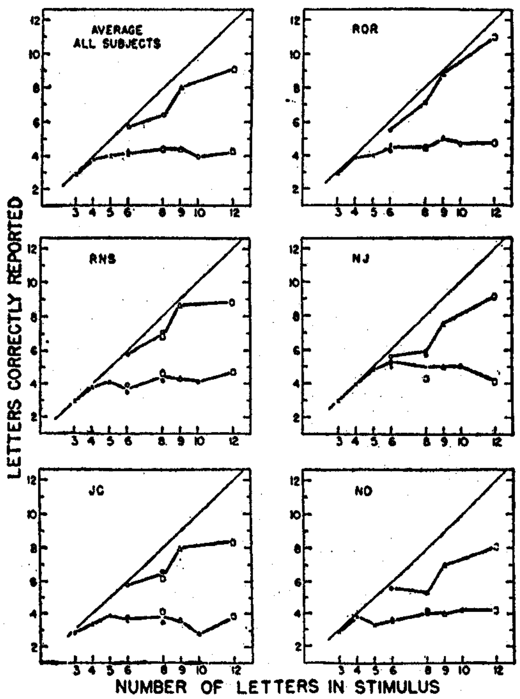

FIG. 3. "Channel capacity curves." Immediate-memory and letters available (output information) as functions of the number of stimulus letters (input information). Lower curves = immediate-memory (Exp. 1); upper curves = letters available immediately after termination of the stimulus; diagonal lines = maximum possible score (i.e., input = output). Code: × = letters on one line; + = 6-massed; o = 3/3, 4/4, 5/5; Δ = 3/3/3; □ = 4/4 L&N, 4/4/4 L&N.

[7] See Sperling (1959) for tables giving the numerical values of all points appearing in this and in all other figures.

equal to the smaller of (*a*) the number of letters in the stimulus or (*b*) a numerical constant—the span of immediate-memory—which is different for each *S*. The use of the term immediate-memory span is therefore justified within the range of materials studied. This limit on the number of letters that can be correctly reported is an individual characteristic, but it is relatively similar for each of the five *S*s of the study.

Experiment 2: Exposure Duration

The results of Experiment 1 showed that, regardless of material, *S*s could not report more than an average of about 4.5 items per stimulus exposure. In order to determine whether this limitation was a peculiar characteristic of the short exposure duration (0.05 sec.), it was necessary to vary the exposure duration.

Procedure. As in the previous experiment, *S*s were instructed to report all the letters in the stimulus. The stimuli were six letter cards (3/3). NJ, who was able to report more than five correct letters in Experiment 1, was given 4/4 stimuli in order to make a possible increment in his accuracy of responding detectable. The *S*s were given 10 trials in each of the four conditions, .015-, .050-, .150- (.200-), .500-sec. exposure duration, in the order above. In a later session, additional trials were conducted at .015-sec. exposure as a control for Experiment 5. These trials are averaged with the above data.

Results and discussion. Figure 4 illustrates the number of letters correctly reported as a function of the duration of exposure. The main result is that exposure duration, even over a wide range, is not an important parameter in determining the number of letters an *S* can recall correctly. Both individually and as a group, *S*s show no systematic changes in the number of letters correctly reported as the exposure duration was varied from 0.015 to 0.500 sec. The invariance of the number of letters reported as a function of exposure durations up to about 0.25 sec. for the kind of presentation used (dark pre- and post-exposure fields) has long been known (Schumann, 1904).

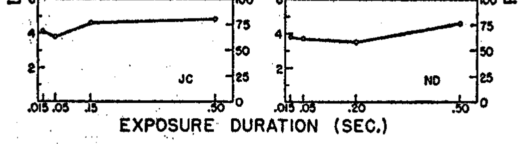

FIG. 4. Letters correctly reported as a function of exposure duration.

Experiment 3: Partial Report

Experiments 1 and 2 have demonstrated the span of immediate-memory as an invariant characteristic of each *S*. In Experiment 3 the principles of testing in a perceptual situation that were advanced in the introduction are applied in order to determine whether *S* has more information available than he can indicate in his limited immediate-memory report.

The *S* is presented with the stimulus as before, but he is required only to make a partial report. The length of this report is four letters or less, so as to lie within *S*'s immediate-memory span. The instruction that indicates which row of the stimulus is to be reported is coded in the form of a tone. The instruction tone is given after the visual presentation. The *S* does not know until he hears the tone which row is called for. This is therefore a procedure which samples the information that *S* has available after the termination of the visual stimulus.

Procedure. Initially, stimulus materials having only two lines were used, that is, 3/3 and 4/4. The *S* was told that a tone would be sounded, that this tone would come approximately simultaneously with the exposure, and that it would be either a high tone (2500 cps) or a low tone (250 cps). If it were a high tone, he was to write only the upper row of the stimulus; if a low tone, only the lower row. He was then shown a sample card of 3/3 letters and given several high and low tones. It was suggested that he keep his eyes fixated on the fixation point and be equally prepared for either tone. It would not be possible to outguess the *E* who would be using a random sequence of tones.

The tone duration was approximately 0.5 sec. The onset of the tone was controlled through the same microswitch that controlled the off-go of the light, with the completion of a connection from an audio-oscillator to the speaker. Intensity of the tone was adjusted so that the high (louder) tone was "loud but not uncomfortable."

In each of the first two sessions, each *S* received 30 training trials with each of the materials 3/3, 4/4. In subsequent sessions *S*s were given series of 10 or more "test" trials. Later, a third, middle (650 cps) tone was introduced to correspond to the middle row of the 3/3/3 and 4/4/4 stimuli. The instructions and procedure were essentially the same as before.

In any given session, each tone might not occur with equal frequency for each type of stimulus. Over several sessions, usually two, this unequal frequency was balanced out so that an *S* had an exactly equal number of high, medium, and low tones for each material. If an *S* "misinterpreted" the tone and wrote the wrong row, he was asked to write what he could remember of the correct row. Only those letters which corresponded to the row indicated by the tone were considered.

Treatment of the Data. In the experiments considered in this section, *S* is never required to report the whole stimulus but only one line of a possible two or three lines. The simplest treatment is to plot the percentage of letters correct. This, in fact, will be done for all later comparisons. The present problem is to find a reasonable measure to enable comparison between the partial report and the immediate-memory data for the same stimuli. The measure, *percent correct,* does not describe the results of the immediate-memory experiments parsimoniously. In Experiment 1 it was shown that *S*s report a constant number of letters, rather than a constant percentage of letters in the stimulus. The measure, *number of letters correct,* is inappropriate to the partial report data because the number of letters which *S* reports is limited by the *E* to at most three or four. The most reasonable procedure is to treat the partial report as a random sample of the letters which the *S* has available. Each partial report represents a typical sample of the number of letters *S* has available for report. For example, if an *S* is correct about 90% of the time when he is reporting three out of nine letters, then he is said to have 90% of the nine letters—about eight letters—available for partial report at the time the instruction tone is given.

In order to calculate the number of available letters, the average number of letters correct in the partial report is multiplied by the number of equiprobable (nonoverlapping), partial reports. If there are two tones and two rows, multiplication is by 2.0; if three, by 3.0. As before, only the number of correct letters in the correct position is considered.

Results. The development of the final, stable form of the behavior is relatively rapid for *S*s giving partial reports. The average for all *S*s after 30 trials (first session) with the 3/3 stimuli was 4.5; on the second day the average of 30 more trials was 5.1. On the third day *S*s averaged 5.6 out of a possible six letters. Most of the improvement was due to just one *S*: ND who improved from 2.9 to 5.8 letters available. In the 3/3/3 stimulus training, all *S*s reached their final value after the initial 40 trials on the first day of training. The considerable experience *S*s had acquired with the partial reporting procedure at this time may account for the quick stabilization. NJ, whose score was 7.7 letters available on the first 20 trials, was given almost 150 additional trials in an unsuccessful attempt to raise this initial score.

In Fig. 3 the number of letters available as a function of the number of letters in the stimulus are graphed as the upper curves. For all stimuli and for all *S*s, the available information calculated from the partial report is greater than that contained in the immediate-memory report. Moreover, from the divergence of the two curves it seems certain that, if still more complex stimuli were available, the amount of available information would continue to increase.

The estimate above is only a lower bound on the number of letters that *S*s have available for report after the termination of the stimulus. An upper bound cannot be obtained from experiments utilizing partial reports, since it may always be argued that, with slightly changed conditions, an improved performance might result. Even the lower-bound measurement of the average available information, however, is twice as great as the immediate-memory span. The immediate-memory span for the 4/4/4 (12-letters and numbers) stimuli ranges from 3.9 to 4.7 symbols for the *S*s, with an average of 4.3. Immediately after an exposure of the 4/4/4 stimulus material, the number of letters available to the *S*s ranged from 8.1 (ND) to 11.0 (ROR), with an average of 9.1 letters available.

This number of letters may be transformed into the bits of information represented by so many letters. For the 4/4/4 (12-letters and numbers) material, the average number of bits available, then, is 40.6, with a range from 36.2 to 49.1 (out of a possible 53.6 bits). These figures are considerably higher than the usual estimates. For example, in a recent review article Quastler (1956) writes: "All experimental studies agree that man can . . . assimilate less than 25 bits per glance" (p. 32). The data obtained in Experiment 3 not only exceed this maximum, but they contain no evidence that the information that became available to the *S*s following the exposure represented a limit of "man" rather than a maximum determined by the limited information contained in the stimuli which were used.

Experiment 4: Decay of Available Information

Part 1: Development of Strategies of Observing

It was established in Experiment 3 that more information is available to the *S*s immediately after termination of the stimulus than they could report. It remains to determine the fate of this surplus information, that is, the "forgetting curve." The partial report technique makes possible the sampling of the available information at the time the instruction signal is given. By delaying the instruction, therefore, decay of the available information as a function of time will be reflected as a corresponding decrease in the accuracy of the report.

Procedure. The principal modification from the preceding experiment is that the signal tone, which indicates to the *S* which row is to be reported, is given at various other times than merely "zero delay" following the stimulus off-go. The following times of indicator tone onset relative to the stimulus were explored: 0.05 sec. before stimulus onset (−0.10 sec.), ±0.0-, +0.15-, +0.30-, +0.50-, +1.0-sec. delays after stimulus off-go. The stimuli used were 3/3, 4/4.

The *S*s were given five or more consecutive trials in each of the above conditions. These trials were always preceded by at least two samples in order to familiarize *S* with the exact time of onset. The particular delay of the instruction tone on any trial was thus fixed rather than chosen randomly. The advantages of this procedure are (*a*) optimal performance is most likely in each delay condition, if *S* is prepared for that precise condition (cf. Klemmer, 1957), (*b*) minimizing delay changes makes possible a higher rate of stimulus presentations. On the other hand, a random sequence of instruction tone delays would make it more likely that *S* was "doing the same thing" in each of the different delay conditions.

The sequence in which the different delay conditions followed each other was chosen either as that given above (ascending series of delay conditions) or in the reverse order (descending series). Within a session, a descending series always followed an ascending series and vice versa, irrespective of the stimulus materials used. At least two ascending and two descending series of delay conditions were run with each *S* and with each material, after the initial training (Experiment 3) with that material. This number of trials insures that for each *S* there are at least 20 trials at each delay of the indicator tone.

Results and discussion. The development of the typical behavior is illustrated by the *S*, ROR, in Figs. 5a, b, c. Figure 5a shows ROR's performance in a single session, the first posttraining session. The upper and lower curves represent the ascending and descending series of tone instruction delays, respectively. The arrows indicate the order. Although each point is based upon only five trials, the curves are remarkably similar and regular. Clearly, most of the letters in excess of ROR's memory span are forgotten within about 0.25 sec. The rapid forgetting of these letters justifies calling this a short-term memory and accounts for the fact that it may easily be overlooked under less than optimal conditions. In the following session (Fig. 5b) the descending series

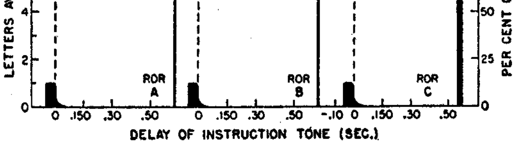

FIG. 5. Partial report of eight (4/4) letters, three consecutive sessions. Arrows indicate the sequence in which conditions followed within a session. The light flash is shown on same time scale at lower left of each figure. Bar at right indicates immediate-memory for this material. One subject (ROR).

was given first. Here orderly behavior disintegrates. In the third session (Fig. 5c) two modifications were introduced: (*a*) the number of trials in each delay condition was increased to eight and (*b*) a new delay condition was given—namely, a signal tone coming 0.05 sec. before the stimulus onset. The curves are again regular, but they are obviously different for the ascending and descending series. For the session indicated in Fig. 5c, an analysis of the errors by position shows that in the ascending series the errors are evenly split between the top and bottom rows of the stimulus; in the descending series, the top row is favored 3:1.

ROR's performance is analyzable in terms of two kinds of observing behavior (strategies) which the situation suggests. He may follow the instruction, given by *E* prior to training, that he pay equal attention to each row. In this case, errors are evenly distributed between rows. Or, he may try to anticipate the signal by guessing which instruction tone will be presented. In this case, *S* is differentially prepared to report one row. If the signal and *S*'s guess coincide, *S* reports accurately; if not, poorly. Such a guessing procedure would lead to the variability observed in Fig. 5b. On the other hand, *S* may prefer always to anticipate the same row—in the case of ROR (Fig. 5c, descending series), the top row. This would again allow reliable scores, provided only that there are an equal number of instruction signals calling for the top and bottom rows. Concomitantly, a differential accuracy of report for the two rows is observed. (ROR's preference for the top row is again prominent in Experiment 7, Figs. 10, 11.)

Equal attention responding is initially reinstated on the third day. The obvious change in procedure which is responsible is the introduction of a tone 0.05 sec. before the stimulus onset (−0.10 sec. "after" its termination). This signal is sufficiently in advance of the stimulus so that perfect responding is possible by looking at only the row indicated by the signal tone. ROR scores 100%, both in this condition and in the succeeding zero delay. The whole (ascending series) decay curve of Fig. 5c is highly similar to that of Fig. 5a. A run with 3/3 stimuli was interposed between the ascending and descending series shown in Fig. 5c. Since the guessing procedures were easily sufficient for a nearly perfect score with 3/3 materials, when the descending series of delay conditions was run, ROR continued guessing. While guessing was advantageous at the long delays, at the short delays it was a decided disadvantage.

Figure 6 illustrates the performances of RNS, a sophisticated observer. RNS described the two strategies (equal attention, guessing) to *E*. In accordance with the instructions to do as well as he could, RNS said that he switched from the first to the second strategy at delays longer than 0.15 sec. Thus in the three short delay conditions, RNS divided his errors almost evenly (19:21) between the favored (top) and the unfavored rows; in the two longer delays, errors were split 4:26. The dip in the curve indicates that RNS did not switch strategies quite as soon as he could have, for optimal performance. Such a dip is

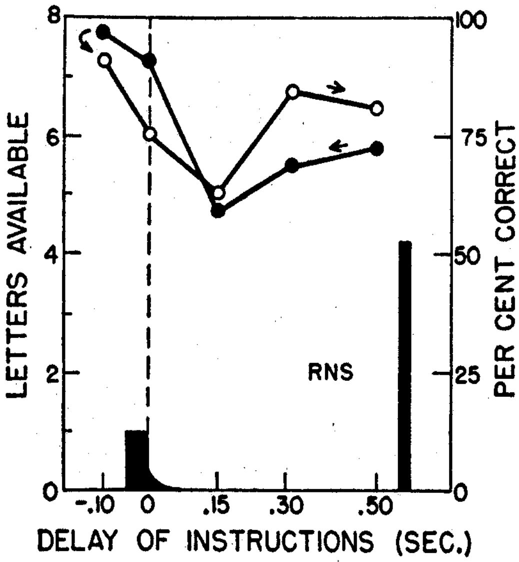

FIG. 6. Partial report of eight (4/4) letters, last of three sessions. Arrows indicate the sequence in which conditions followed within session. The light flash is shown on same time scale at lower left. Bar at right indicates immediate-memory for this material. (RNS)

characteristically seen in experiments of this kind.

The other *S*s exhibit similar curves.[8] These are not presented, as the main features have already been demonstrated by ROR and RNS. In summary, the method of delaying the instruction tone is a feasible one for determining the decay of the short-term memory contents, but experience with the difficult, long delays causes a considerable increase in the variability of *S*s' performance which is carried over even to the short delay conditions. This has been attributed to *S*s' change from an equal attention to a guessing strategy in observing the stimulus.[9]

Part 2: Final Level of Performance

The analysis of the preceding experiment has indicated that two distinct kinds of observing behavior develop when the instruction to report is delayed. The accuracy of report resulting from the first of these behaviors (equal attention) is correlated with the delay of the instruction tone; it is associated with the *S*s initially giving equal attention to all parts of the stimulus. The accuracy of the other kind of report (guessing) is uncorrelated with the delay of the instruction; it is characterized by *S*s' differential preparedness for some part of the stimulus (guessing). Equal attention observing is selected for further study here. The preceding experiment suggests three modifications that would tend to make equal attention observing more likely to occur, with a corresponding exclusion of guessing.

1. The use of stimuli with a larger number of letters, that is, 3/3/3 and 4/4/4. Differential attention to a constant small part of the stimulus is less likely to be reinforced, the larger the stimulus. The use of three tones instead of two diminishes the probability of guessing the correct tone.

2. Training with instruction tones that begin slightly before the onset of the stimulus. It is not necessary for *S* to guess in this situation since he can succeed by depending upon the instruction tone alone. This situation not only makes equal attention likely to occur, but differentially reinforces it when it does occur.

When delays of longer length are tested, priority should be given to an ascending series of delays so that *S* will, at the beginning of a particular delay sequence, have a high probability of entering with the desired observing behavior. This probability might be nearly 1.0 by interposing a series of trials on which the instruction is given in advance of, or immediately upon, termination of the stimulus and requiring that *S* perform perfectly on this task before he can continue to the particular delay being tested.[10] This tedious procedure was tried; but, as it did not have an appreciable effect upon the results, it was discontinued. The problem is that *S*s learn to switch between the two modes of behavior in a small number of trials.

3. The *E* may be able to gain *verbal* control over *S*s' modes of responding. Initially, however, even *S* cannot control his own behavior exactly. This suggests a limit to what *E* can do. For example, frequently *S*s reported that, although they had tried to be equally prepared for each row, after some tones they realized that they had been selectively prepared for a particular row. This comment was made both when the tone and the row coincided and (more frequently) when they differed.

[8] See Sperling (1959) for tables containing individual averages of all trials for each *S* at each delay of instruction tone: 3/3, 4/4.

[9] Increase in variability (with consequent decrement in accuracy and/or speed) is not unusual after difficult conditions. For example, Cohen and Thomas (1957) in a clinically oriented study have reported an exactly analogous "hysteresis" phenomenon in a study of discriminative reaction time. Hysteresis refers to the fact that, when the difficulty of an experimental task is changed, the corresponding change in accuracy of response lags behind the change in task.

[10] It takes, on the average, a very large number of trials for *S* to get 10 consecutive perfect trials even if he has 6 or 7 of 9 letters available or knows with 2/3 probability what the tone will be. Success in this task within a reasonable time limit demands a level of excellence reached only with "equal attention" observing, as judged by the other criteria.

Some verbal control is, of course, possible. An instruction that was well understood was:

> You will see letters illuminated by a flash that quickly fades out. This is a visual test of your ability to read letters under these conditions, not a test of your memory. You will hear a tone during the flash or while it is fading which will indicate which letters you are to attempt to read. Do not read the card until you hear the tone, [etc.].

The instruction was changed at the midway point in the experiment. The *S* was no longer to do as well as he could by any means, but was limited to the procedure described above. Part 2 of this experiment, utilizing 9- and 12-letter stimuli, was carried out with the three modifications suggested above.

Results. The results for 3/3/3 and 4/4/4 letters and numbers are shown for each individual *S* in Figs. 7 and 8. The two ordinates are linearly related by the equation:

$$\frac{\text{percent correct}}{100} \times \text{no. letters in stimulus} = \text{letters available}$$

Each point is based on all the test trials in the delay condition. The points at zero delay of instructions for NJ and JC also include the training trials, as these *S*s showed no subsequent improvement.

The data indicate that, for all *S*s, the period of about one sec. is a critical one for the presentation of the instruction to report. If *S*s receive the instruction 0.05 sec. before the exposure, then they give accurate reports: 91% and 82% of the letters given in the report are correct for the 9- and 12-letter materials, respectively. These partial reports may be interpreted to indicate that the *S*s have, on the average, 8.2 of 9 and 9.8 of 12 letters available. However, if the instruction is delayed until one sec. after the exposure, then the accuracy of the report drops 32% (to 69%) for the 9-letter stimuli, and 44% (to 38%) for the 12-letter stimuli. This substantial decline in accuracy brings the number of

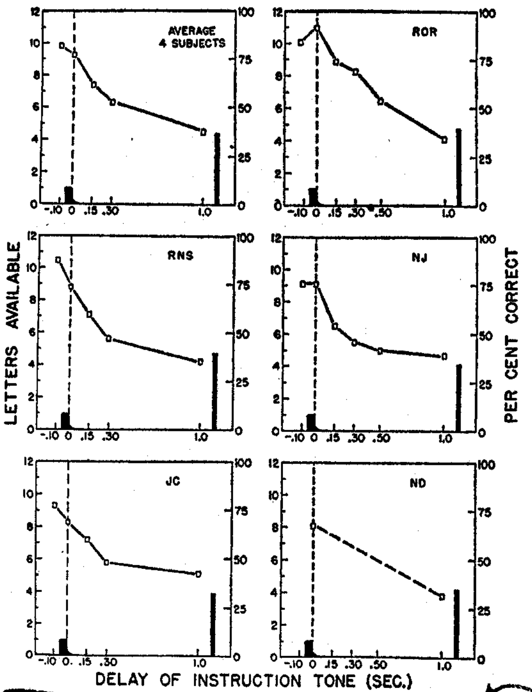

FIG. 7. Decay of available information: nine (3/3/3) letters. Light flash is shown on same time scale at lower left. Bar at right indicates immediate-memory for this material.

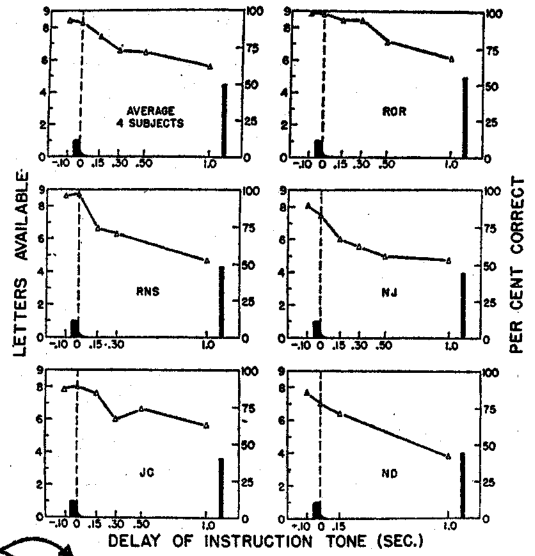

FIG. 8. Decay of available information: twelve (4/4/4) letters and numbers. Light flash is shown on same time scale at lower left. Bar at right indicates immediate-memory for this material.

letters available very near to the number of letters that *S*s give in immediate-memory (whole) reports.

The decay curves are similar and regular for each *S* and for the average of all *S*s. Although individual differences are readily apparent, they are small relative to the effects of the delay of the instruction. For example, when an instruction was given with zero delay after the termination of the stimulus, the *least* accurate reports by any *S*s are given by ND, who has 8.1 letters available immediately after the termination of the stimulus. With a one-sec. delay of instructions, the *most* accurate reports were given by JC, who has only 5.1 letters available at this time.

In Fig. 3, in which whole reports and partial reports were compared, only that particular partial report was considered in which the instruction tone followed the stimulus with zero delay. It is evident from this experiment that the zero delay instruction is unique only in that it is the earliest possible "after" instruction, but not because of any functional difference.

In Fig. 9, therefore, the 0.15-, 0.50-, and 1.00-sec. instruction delays are also plotted for one *S*, ROR. Data for the six- (3/3) and eight- (4/4) letter stimuli are taken from the two ascending delay series with each material that yielded monotonic results. Figure 9 clearly highlights the significance of a precisely controlled coded instruction, given within a second of the stimulus off-go, for the comparison of partial and immediate-memory reports. One second after termination of the stimulus, the accuracy of ROR's partial reports is no longer very different from the accuracy of his whole reports.

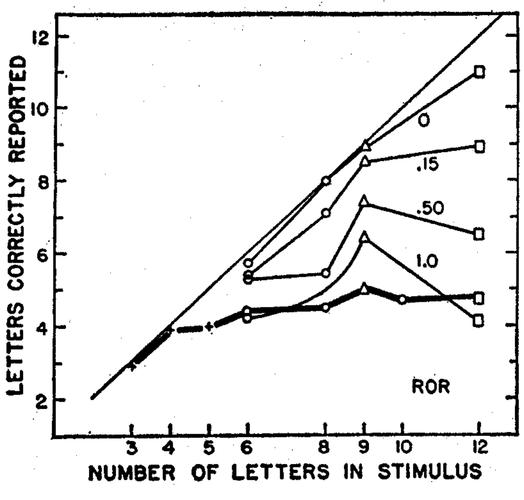

FIG. 9. Immediate-memory and available information. The parameter is the time at which available information is sampled (delay of instruction). Heavy line indicates immediate-memory for the same materials. One subject (ROR).

Experiment 5: Some Exposure Parameters

In Experiment 3 it was shown that the number of letters reported correctly is almost independent of the exposure duration over a range from 15 to 500 msec. It is well known, however, that the relation between the accuracy of report and the exposure duration depends upon the pre- and post-exposure fields (Wundt, 1899).

In a technique developed in Helmholtz's laboratory (Baxt, 1871) the informational (stimulus) field is followed, after a variable delay, by a noninformational, homogeneous, bright post-exposure field. Using this method, Baxt showed that the number of reportable letters was a nearly linear function of the delay of the bright post-exposure field.[11]

Other combinations of pre- and post-exposure fields have also been tried (Dodge, 1907a). The usual tachistoscopic presentation utilizes gray pre- and post-exposure fields (Woodworth, 1938). Baxt's procedure, however, is the most disadvantageous for the observer. A similar procedure was therefore selected, in order

[11] This important method was described by Ladd (1899) and James (1890) in their textbooks, but it is no longer well known. Consequently it has been "rediscovered," most recently, by Lindsley and Emmons (1958). Baxt (1871) intended that the bright second field would interfere with the lingering image of the first (informational) field. Unfortunately, the effect depends in a complex way upon the intensity of the two fields. Derived time values must be used with caution. In some cases the Baxt technique may actually result in no loss of legibility, the second field producing a negative "afterimage" instead of merely interfering with the positive image (cf. Footnote 15).

to study whole and partial reports in a vastly different visual presentation from that of the previous experiments.

Procedure. 1. *S*s were instructed to write all the letters of the stimulus; 3/3 stimuli were used. After several sample presentations of a stimulus card followed by a light post-exposure field, *S*s were given a random sequence of normal (pre- and post-exposure fields dark) and Baxt (pre-exposure dark, post-exposure field light) trials. The Baxt trials do not correspond exactly to the presentation that Baxt used. In this experiment, the post-exposure field is the same intensity as the stimulus (informational) field, whereas Baxt usually used more intense post-exposure fields; also, the stimulus field always remains *on* until the onset of the post-exposure field, whereas Baxt used a fixed five-msec. duration for the stimulus field. The post-exposure field itself remains on for about one sec. The pre-exposure field is always dark, as in all the previous experiments. Two exposure durations, 0.015 and 0.050 sec., were tested.

2. Three *S*s were tested with the Baxt presentation of a 3/3/3 stimulus at an exposure duration of 0.015 sec. The partial report procedure was used to determine the effects of the post-exposure field on the number of letters available.

3. The same three *S*s were run as their own controls. The procedure was exactly the same as in Paragraph 2 above except that the post-exposure field was normal (dark).

Results. The complete results are given in Tables 1 and 2. In all tests, the Baxt procedure reduces the response accuracy of all *S*s to about one-half of their normal score. This finding confirms the earlier studies. However, a linear relation between exposure duration and the number of letters reported was not observed. The failure to find a linear relation may be due to the previously mentioned differences between the presentations.

For RNS and ND, the number of letters available is nearly the same (about two) in the partial report of 9-letter stimuli as the whole report of 6-letter stimuli. The fact that in both procedures the number of letters given by *S*s is the same suggests that a Baxt presentation reduces the number, or the length of time that letters are available, and that it does not directly affect the immediate-memory span.

ROR's partial reports of Baxt presentations are considerably more accurate than those of the other *S*s, although they are not as accurate as his reports in control presentations. ROR seemed to show improvement on successive Baxt trials. JC, another *S* who seemed to show improvement, was given additional Baxt trials on which he continued to improve slowly. Unfortunately, it was unfeasible to determine the asymptotic performance of these two *S*s. Whether the difference in performance between ROR, and RNS and ND is attributable to some overt response, such as squinting or blinking, was not determined.

TABLE 1

A Comparison of Response Accuracy with Two Different Post-Exposure Fields

Subject	Exposure (sec.)	Normal	Baxt
RNS	(0.015)	3.9	2.5
	(0.050)	4.0	2.2
ROR	(0.015)	4.8	3.5
	(0.050)	4.4	2.8
ND	(0.015)	3.8	1.9
	(0.050)	3.7	2.3
NJ	(0.015)	5.1	2.4
	(0.050)	5.4	3.4
JC	(0.015)	4.1	2.7
	(0.050)	3.8	3.4
Mean	(0.015)	4.3	2.6
	(0.050)	4.3	2.8

Note.—Number of letters correctly reported. Whole report of six (3/3) letter stimuli. Normal = pre- and post-exposure fields dark; Baxt = pre-exposure field dark, post-exposure field white.

Table 2 also enables the comparison of 0.015- and 0.050-sec. exposures of 3/3/3 stimuli. A decrease in exposure duration has only a slight effect on the number of letters available. This suggests, as in the immediate-memory experiments, that the duration of a tachistoscopic exposure is not as important a determinant of the number of letters available as the fields which follow the exposure.

Experiment 6: Letters and Numbers

In Experiment 3 partial reports were found to be uniformly more accurate than

TABLE 2

A Comparison of Response Accuracy with Two Different Post-Exposure Fields

Delay of Instruction (sec.):	0.0		0.15	
Exposure Duration (sec.): Subject	0.015	0.05	0.015	0.05
RNS (N)	8.0	8.7	5.4	6.6
(B)	2.0		2.2	
ROR (N)	8.6	8.9	8.3	8.5
(B)	6.3		5.4	
ND (N)	7.3	7.0	5.8	6.4
(B)	2.2		1.7	
Mean (N)	8.0	8.2	6.5	7.2
(B)	3.5		3.1	

Note.—Number of letters available (fraction of letters correct in partial report × number of letters in stimulus). Stimuli: nine (3/3/3) letters. (N) = normal (pre- and post-exposure fields dark), (B) = Baxt (pre-exposure field dark, post-exposure field white).

whole reports. In one case, stimuli of eight letters were used and only one row of four letters was reported. Designating the letters to be reported by their location is only one of a number of possible ways. In the following experiment, a quite similar set of stimuli is used; each stimulus has two letters and two numbers in each of the two rows. The partial report again consists of only four symbols, but these are designated either as letters or as numbers rather than by row. In addition, a number of controls which are also relevant to Experiment 3 are conducted.

Procedure. I. Training: The *S*s were given practice trials with the instruction: "Write down only the numbers if you hear a short pip (tone 0.05-sec. duration) and only the letters if you hear the long tone (0.50-sec. duration)." The tones were then given with zero delay following the stimulus off-go. The stimuli were 4/4 L&N.

II. In the following session, tests were conducted with five different instructions:

1. Letters only—Instructions given well in advance of stimulus to write only the letters in the following card(s). (8 trials)

2. Numbers only—Write only the numbers in the following card(s). (8 trials)

3. Top only—Write only the top row in the following card(s). (4 trials)

4. Bottom only—Write only the bottom row in the following card(s). (4 trials)

5. Instruction tone—Write either letters or numbers as indicated by tone. Tone onset 0.05 sec. before stimulus onset. (16 trials) ROR was also given additional trials at longer delay times.

Results. The results are illustrated in Table 3. For purposes of comparison, the number of correct letters is multiplied by two when an instruction was used which required *S* to report only four of the eight symbols of the stimulus. This includes instructions given well in advance of the stimulus. All measures, then, have 8.0 as the top score and are thus equivalent within a scale factor to percent correct measures. The range is 0-8 instead of 0-100. Scores which are based on partial reports are therefore directly comparable to the partial report scores (letters available) obtained in Experiments 3, 4, and 5.

When stimuli consist of letters and numbers, but *S*s report only the letters or only the numbers, then the *S*s' partial reports are only negligibly more accurate than their whole reports of the same stimuli. The average number of letters available (calculated from the partial report) is just 0.2 letter above the immediate-memory span

TABLE 3

COMPARISON OF FIVE PROCEDURES

Subject	Letters only	Numbers only	Average L&N	Instr. tone −0.10	Immediate-memory	One row only
RNS	5.0	4.5	4.8	4.3	4.6	7.3
ROR	6.5	6.5	6.5	6.3	4.5	7.3
ND	3.5	3.8	3.6	4.1	4.1	7.5
NJ	4.0	5.0	4.5	4.6	4.3	—
JC	3.3	4.0	3.6	3.4	4.1	8.0
Mean	4.5	4.8	4.6	4.5	4.3	—

Note.—Average letters and/or numbers available (fraction of letters—numbers—correct in partial report × number of symbols in stimulus). Stimuli: eight (4/4) letters and numbers.

for the same material. For practical purposes, the partial report score is the same score that *S*s would obtain if they wrote all the letters and numbers they could (that is, gave a whole report) but were scored only for letters or only for numbers, independently by the experimenter. The partial report of letters only (or of numbers only) does not improve even when the instruction is given long in advance verbally instead of immediately before the exposure by a coded signal tone.

The estimate of the number of available letters and numbers which is obtained from the partial report of letters (or numbers) only is also the same as the estimate that would be obtained if, on each trial, *S*s wrote only one row—either the top or the bottom—according to their whim. Reporting only one row of four letters and numbers is a task at which the *S*s succeed with over 90% accuracy. Even if they are scored for the whole stimulus, by arbitrarily reporting only one row they would still achieve a score of almost 50% correct or almost four letters available. This is why no delay series were conducted. If *S*s had ignored the instruction to write only the letters (or numbers) and had written only a single row on each trial, they would have shown less than a 0.5 letter decrement, no matter what the delay of the instruction.

Only ROR showed a substantial improvement when reporting only the numbers (or letters). He was the only *S* with whom it made sense to conduct a systematic delay series, although checks with other *S*s confirmed this conclusion. Table 4 indicates that two extra symbols are available to ROR for report only when the tone is given before the stimulus, but not if it is given immediately after. It should be noted that the information in the instruction tone comes only after it has been on for 0.05 sec. At this time it either continues or is terminated. The actual "instruction" is thus given 0.05 sec. after the tone onset. ROR therefore requires that the *instruction* be given within 0.05 sec. of the stimulus termination if any benefit of the partial report procedure is to be retained.

Whether the *S*s would have shown improvement with a large amount of additional training in the partial report of letters or numbers cannot be stated. Table 3 shows that, when *S*s are required in advance to report only one row, this task is trivial. The substantial advantage of partial reports of rows (report by position) over partial re-

TABLE 4

PARTIAL REPORTS OF LETTERS OR NUMBERS

Subj.	Prior Verbal Instr.	Delay of Instr. Tone (sec.) −0.10	0.0	+0.25	Immediate Memory
ROR	6.5	6.3	4.7	4.4	4.5

Note.—Average of symbols available (fraction of letters—numbers—correct in partial report × number of symbols in stimulus). Stimuli: eight (4/4) letters and numbers.

ports of numbers or letters (report by category) when the instruction is given verbally long in advance of the exposure is retained even when the instruction is coded and given shortly after the exposure.

The failure in Experiment 6 to detect a substantial difference in accuracy between partial reports of only letters (or only numbers) and whole reports clearly illustrates that partial reports by position are more effective for studying the capacity of short-term information storage than partial reports by category.

Experiment 7: Order of Report

Interpretations of the effects of instructions upon the report following a single brief visual exposure have often been concerned with either the perceptual sensitizing effects of an instruction given before the exposure or with the importance of forgetting between the exposure and a post-exposure instruction to report. The decay curves of Experiment 4 include both of these effects. Previous studies, however, have usually assumed the order in which the various parts (aspects, dimensions, etc.) of the stimulus are reported to be the significant correlate of post-exposure forgetting. The possibility that information might be well retained even though not immediately reported has been mentioned (Broadbent, 1958), but experimental investigations of such an effect by an independent variation of the order of report by Wilcocks (1925), Lawrence and Laberge (1956), and Broadbent (1957a) have apparently shown otherwise. Broadbent (1957a) has also shown a case in which independent variation of the order of report did not reduce overall response accuracy.

In the present experiment, order of report is introduced as a purely "nuisance" variable for the *S*. The *S* is instructed to get as many letters correct as possible, but the *E* randomly manipulates the order in which they are to be reported. The experiment is a survey of how *S*s adapt to this kind of interference with the normal order of their report.

Procedure. The *S*s were instructed to write the row indicated by the tone (high, low) first, then to write the other row. They were to try to get as many *total* letters correct as possible, it being of no importance in which particular row the correct letters might be. The instruction tone was given with 0.0-, .30- (or .50-), and 1.0-sec. delay after the termination of the stimulus.

Controls. In addition to the trials with a high or low tone, two sets of 8 (or 10) trials were given with a neutral, middle tone. The instruction was: "Write all the letters in any order you wish, but do not begin writing until you hear the tone." The tone was sounded with 0.0-sec. delay following termination of the stimulus and also with 1.0-sec. delay. It bears repeating here that *S*s were not permitted just to mark X's but were required to guess various letters.

Results. Controls: The instruction which required *S*s to wait for 1.0 sec. before beginning to write their answer was ignored by the *S*s, since it was almost physically impossible to begin writing sooner. Consequently the two different controls—trials on which *S* was required to "wait" for 1.0 sec. and trials on which *S* could begin his report immediately—are grouped together. These data, which are almost exactly the same as the memory span data (Experiment 1), are presented on the far right in Fig. 10.

The *S*s' responses on the control trials are analyzed in terms of the correlation between the location of letters on the stimulus and the accuracy of the report of these letters in the response. The symbols T and B above I-M in Fig. 10 represent the percentage of the letters of the top and of the bottom rows that *S*s report correctly. The middle point is the average percentage of the letters of the top and bottom rows that were correctly reported by *S*s. The middle point is therefore also the average percentage correct of all the letters that were reported. Figure 10 shows that all *S*s report the top row of the stimulus more accurately than the bottom row, if they are not instructed with regard to the order in which they must report the rows.

The average accuracy with which *S*s report the top and the bottom rows, when instructions to report one or the other of these rows are given with various delays after the exposure, is also illustrated in

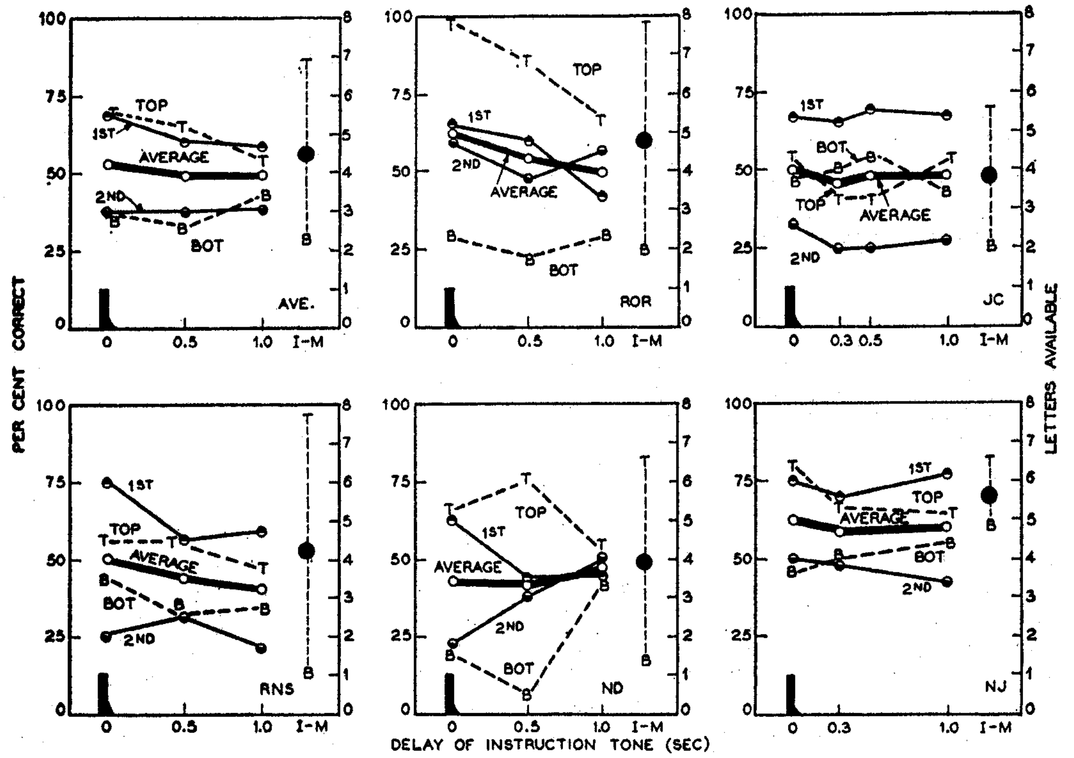

FIG. 10. Accuracy of the first (second) row reported and of the top (bottom) row as a function of the delay of the instruction to report one row first. Light flash is indicated at lower left; immediate-memory (I-M) at right.

Fig. 10. The accuracy of reports of the top row decreases slightly as the delay of the instructions increases. In other respects, however, the data show no systematic changes in accuracy with changes in the delay of instructions. The data clearly indicate that the top row is generally reported more accurately than the bottom row although the instruction to report each row is given with equal frequency.

The same data may also be analyzed with regard to the accuracy of the row that must be reported first and the row that is reported last. All *S*s except ROR are more accurate when they report the first row (the row called for by the instruction tone) than the second row. For most *S*s, therefore, the order of report is correlated with the accuracy of report.

There is a slight tendency for the accuracy of report of the row which is reported first to decrease as the delay of the instructions increases. On the whole, however, the overall accuracy of report decreases slightly with the delay of the instruction to report one row first. The experimental interference with the normal order of report does not change the overall number of letters reported correctly by any *S* by more than about 0.5 letter.

In this task, unlike the preceding ones, individual differences are more striking than the similarities. The pooled data are highly untypical of three of the five *S*s. Figure 11 was devised as a two-dimensional, graphical analysis of variance to compress the details of Fig. 10 into one figure.[12] Each coordinate represents the accuracy of

[12] Figure 11 is based upon a suggestion by E. B. Newman. A statistical analysis of variance was not attempted since it would have had to be carried out separately on each *S*. There was not enough data to make this worthwhile, and Fig. 11 serves the same purpose.

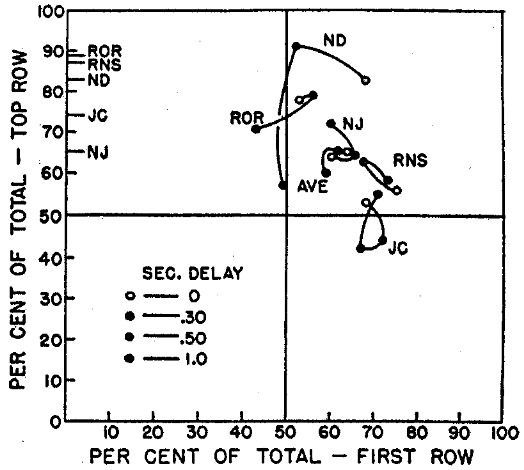

FIG. 11. Graphical analysis of position on stimulus vs. order of report as contributors to response accuracy. Each point represents the average of all trials of an S at a particular delay of instruction. The order in which the points are connected corresponds to the magnitude of the delays. Upper left: position preference in control (immediate-memory) report.

one row of the report relative to the whole report. Thus the ordinate represents the number of letters that an individual S reports correctly in the top row of the stimulus (independently of order) divided by the total number of letters (both rows) that he reports correctly. Similarly, the abscissa represents the percentage of the total correct letters reported by S that are contained in his report of the first row. Since each coordinate is relative to S's own accuracy, no point of the graph is inaccessible to S provided that, if necessary, he is willing to sacrifice some accuracy. Since the interference with S's order of report in this experiment had only slight effects on the overall accuracy of S's report, this method of presenting the data is justifiable.

From Fig. 11 it is immediately evident that, for example, 50% of the correct letters that JC reports are from the top row and, by implication, 50% are from the bottom row of the stimulus. More than 70% of the correct letters that JC reports are in the first row reported by him. ROR represents the converse, preferring to report the top row accurately, remaining indifferent to whether it is called for first or last. Other Ss lie between these extremes, each S maintaining approximately the same relative accuracy for the top and the first rows throughout the various delay conditions. Each S, therefore, operates within a characteristic, limited area of the graph. ND is an exception. At zero delay of the instruction tone, both position and order account heavily for the correct letters reported by ND. At 0.5-sec. delay, ND ignored the order (preferring to concentrate on the top row), and at 1.0-sec. delay she lost her position (top row) preference as well. In these three conditions, the total number of letters correctly reported by ND remained approximately the same, within 0.5 letter of the control condition. At 1.0-sec. delay *neither position nor the order contribute to ND's accuracy of report.*

All Ss operate in the upper right quadrant of Fig. 11. This illustrates the finding that no S consistently reported the bottom row more accurately than the top, nor the last row better than the row first called for by the instruction tone. It does not, of course, indicate that Ss could not report the bottom row or the last row more accurately under other conditions. While Ss normally behave quite consistently, the data of ND show that they may try a number of different procedures. The instructions given the Ss prior to the experiment were not restrictive. No specific procedure for making a report was suggested to the Ss, because the purpose of the experiment was to find out how Ss respond when they are not given detailed instructions. With suitable instructions, training, and reinforcements, Ss could probably be induced to make most of the possible kinds of reports that can be diagramed by Fig. 11. This remains an empirical problem.

The results obtained in this experiment support the conclusions that both a position preference and the order of report ordinarily correlate with the accuracy of response, but that probably *neither are necessary* conditions for response accuracy. Some Ss can relinquish the position preference and a favorable order of report with no appreciable decrement in accuracy. This finding is in opposition to Lawrence and Laberge's (1956) contention that accuracy is accounted for by the order of report. Accuracy and order are often correlated, but if a favorable order of report is not *necessary* for accuracy, then it cannot be the cause of accuracy.

When *S* is given a signal indicating which row is to be reported first (Experiment 7), the accuracy of report of the row indicated by the signal (the first row reported) may be compared to the accuracy of the partial report (Experiment 3). The overt procedure on each trial is quite similar in Experiments 3 and 7. The only difference is that in the order of report experiment, after the *S*s have finished writing the row indicated by the signal, they must also write down the other row. In the partial report procedure they do not have to write the second row. The partial report and the order of report experiments also share a common dependent variable: the accuracy of report of the row indicated by the instruction signal.

In view of the similarity in procedure, it is surprising that the accuracy of this common datum should be so different in the two experiments. For example, when *S*s give only the partial reports (the instruction signal being given immediately after termination of the stimulus), then they report 90% of the letters correctly in one row of 4/4 stimuli. When they are required to write the other row also, then they report only 69% of the first four letters correctly. Every *S*, individually, gives a more accurate partial report (Experiment 3) than a report of the first row—of two rows to be reported (Experiment 7). The consistent superiority of the partial report over the first half of a whole report prevails even when the instruction to report is delayed for 0.5 (or 0.3) sec. In all cases where data are available, each *S* reports a row of four letters more accurately when he does not have to write another row of four letters afterwards. That what *S*s must write later should affect the accuracy of what they write first must be explained—if we disregard teleological explanation—by the effect of prior instructions on the accuracy of the report. In other words, if order of report is effective in determining the accuracy of report, then this effect must be a function of instructions given prior to any report at all. For some *S*s, no effect of order of report upon response accuracy was observed.

The two findings, that partial reports are uniformly more accurate than whole reports and that order of report may be uncorrelated with accuracy, contradict Lawrence and Laberge's conclusion that "partial" reports are essentially similar to "first" reports. In fact, the second finding (that in some circumstances order of report and accuracy of report are not correlated) provides a direct counterexample to their conclusion. Their different results may be in part due to the vastly different stimuli which they used. Lawrence and Laberge's entire stimuli each contained less information than two randomly chosen letters.

Discussion

In all seven experiments, *S*s were required to report the letters of briefly exposed lettered stimuli. Two kinds of reports were explored: *partial reports,* which required the *S*s to report only a specified part of the stimulus, and *whole reports,* which required the *S*s to report all the letters of the stimulus. Experiment 3 demonstrated that the accuracy of partial reports was consistently greater than the accuracy of whole reports. Another important difference between partial and whole reports is the correlation of accuracy with the delay of the instruction to report. This was shown in Experiment 4 in which the time delay of the instruction signal, which indicated the row of the stimulus to be reported, was varied. The accuracy of the partial report was found to be a sharply decreasing function of the time at which the instruction was given. If the instruction signal was delayed for one sec. after the exposure, the accuracy of the partial report was no longer very different from that of the whole report. In Experiment 7 it was shown that the accuracy of the whole report does not change as the time of the signal to report is varied—over the same range of time—up to one sec. after the exposure.

The two kinds of report can also be considered in terms of the information (in these experiments, letters) which they indicate the *S* has available for report. In the whole report, the *S* reports all the information that he can. When he gives a partial report, the *S* may have additional available information that is not required for the report. A calculation of the information available to the *S*s for their partial reports indicates that between two and three times more information is available for partial reports than for the whole reports. This discrepancy between the two kinds of report is short-lived. Information in excess of that indicated by the whole report was available to the *S*s for only a fraction of a second following the exposure. At the end of this time, the accuracy of partial reports is no longer very different from that of whole reports.

The whole report has already been extensively studied by psychologists. The maximum number of items an individual can give in such a report is called his *span of immediate-memory;* whole reports are usually called *immediate-memory reports.* Experiments 1 and 2 extend the well-known conclusions that the span of immediate-memory is an individual characteristic and that it is constant over a wide range of stimuli and exposure conditions. Although, in immediate-memory experiments, items are conventionally presented sequentially, Experiments 1 and 2 illustrate that this is not necessary—that a simultaneous presentation may also give results characteristic of immediate-memory experiments.

The main problems to be considered here concern the partial–whole report discrepancy: (*a*) Why is the partial report more accurate than the whole report? (*b*) Why does the partial report retain this added accuracy only for a fraction of a second after the exposure?

The answers proposed are a systematic elaboration of an observation that is readily made by most viewers of the actual tachistoscopic presentation. They report that the stimulus field appears to be still readable at the time a tone is heard which follows the termination of the stimulus by 150 msec. In other words, the subjective image or sensation induced by the light flash outlasts the physical stimulus at least until the tone is heard. The stimulus information is thus "stored" for a fraction of a second as a persisting image of the objective stimulus. As the visual image fades, its legibility (information content) decreases, and consequently the accuracy of reports based upon it decreases.

There is other evidence, besides such phenomenological accounts, that suggests that information is available in the form of an image for a short time after extinction of the physical stimulus. In the first place, it is inconceivable that the observers should stop seeing the stimulus at exactly the moment the light is turned off. The rise and fall of sensation may be rapid, but they are not instantaneous. The question is not *whether* the observer continues to see the stimulus after the illumination is turned off, but for *how long* he continues to see the stimulus. A number of different kinds of psychophysical measurements of the rise and fall of sensation have been attempted. These estimates of the persistence of the visual sensation vary from a minimum of 0.05 sec. (Wundt, 1899) to almost one sec. (McDougall, 1904). The most representative estimates are in the neighborhood of 1/6 sec. (cf. Piéron, 1934), a figure that is in good agreement with the results.[13]

[13] Measurements of the persistence of sensation have almost invariably used techniques which have at most questionable validity. Wundt's method depends upon masking, the effect of the persisting stimulus upon another stimulus. The masking power of a stimulus may be quite different from its visibility. McDougall's measurements, as well as those cited by Piéron, depend upon motion of a stimulus across the retina. Such measurements are undoubtedly influenced by the strong temporal and spatial interactions of the eye (Alpern, 1953). Schumann's ingenious application of the method of Baxt to the determination of persistence is probably the only experiment that utilizes pattern stimulation. The other methods have not been tried with pattern stimuli although there is, a priori, no good reason why they have not been. The possibility that the persistence of pattern information is quite different from persistence of "brightness" has not been investigated.

In Experiment 5 it was shown that the post-exposure field strongly influences the accuracy of both the partial and the whole report. This experiment indicates that the available information is sensitive to interference by *noninformational visual stimuli* which follow the exposure. The dependence of available information upon noninformational visual stimulation is just the dependence that would be expected of a visual image.

Finally, there are subtle aspects of the sequence of letters reported by an *S* which characterize the information that is available to him. In sequentially spoken letters, for example, there is a limit—two—on the number of letters that can be adjacent to any given letter. Different limits apply to a two-dimensional visual display. If information is stored in a form topologically similar to the stimulus, this may be detected by noting the sequential dependencies that limit successive responses to the stimulus.

Probably the kinds of sequential responding that would most clearly distinguish visual from auditory information storage would be (*a*) the ability of the *S* to read the rows of the visual stimulus backwards as well as forwards, or to report the columns or the diagonals, and (*b*) his inability to do an equivalent task when presented with the information sequentially. (All these procedures merely require the report of adjacent letters if the stimulus is two dimensional.) Unfortunately, these particular experiments were not conducted.

The foregoing experiments offer some relevant evidence. In contrast to spoken letters and numbers, which are most accurately recalled if they occur at the beginning or end of a sequence (Pollack, 1952),[14] no obvious gradients of accuracy were found in the foregoing experiments. The middle row actually tended to be slightly better reported than the other rows. Therefore, it is unlikely that the *entire* visual stimulus (12-letters and numbers) was transformed into an auditory (sequential) representation for storage. Such an entire transformation is also unlikely, though not impossible, because of the relatively small time between the stimulus exposure and the report.

An analysis of errors reveals numerous cases of errors that may be classified as "misreading" (for example, confusions between E and F, B and R) and as "mishearing" (for example, confusions between B and D, D and T—Miller & Nicely, 1955). Still other confusions (for example, C and G) are ambiguous. All of these types of errors occurred whenever errors occurred at all. The ubiquity of misreading and mishearing errors, taken at face value, suggests that both visual and auditory storage of information are always involved in both whole and partial reports. A nonquantitative error analysis is therefore not likely to shed much light on the question of visual imagery. The frequent mishearing errors suggest that the storage of letters, just prior to a written report, may share some of the characteristics of audition. Like the preceding analysis of the constraints upon successive responses, error analysis requires considerable research before it can be quantitatively applied to problems of imagery.

This then is the evidence—phenomenological reports, the effects of the post-exposure fields, the known facts of the persistence of sensation, and the detailed characteristics of the responses—that is consistent with the hypothesis that information is initially stored as a visual image and that the *S*s can effectively utilize this information in their partial reports. In the present context, the term, visual image, is taken to mean that (*a*) the observer behaves as though the physical stimulus were still present when it is not (that is, after it has been removed) and that (*b*) his behavior in the absence of the stimulus remains a function of the same variables of visual stimulation as it is in its presence. The units of a visual image so defined are always those of an equivalent "objective image," the physical stimulus. It is as logical or illogical to compute the information contained in a visual image (as was done in Experiments 3 and 4) as it is to compute the information in a visual stimulus.

[14] Summarized in Luce (1956).

"Visual image" and "persistence of sensation" are terms suggested by the asynchrony between the time during which a stimulus is present and the time during which the observer behaves as though it were present. Although asynchrony is inevitable for short exposure durations, there is, of course, no need to use the term "visual image" in a description of this situation. One might, for example, refer simply to an "information storage" with the characteristics that were experimentally observed. This form of psychological isolationism does injustice to the vast amount of relevant researches.

Imagery that reputedly occurs long after the original stimulation (memory images, eidetic images, etc.) is of interest as well as imagery that occurs for only a few tenths of a second following stimulation. Whether the term "imagery," as it has been used here to describe the immediate effects of brief stimulation, is an appropriate term for the description of the lasting effects of stimulation is an empirical problem. It is hoped, however, that the principles and methods developed here will not be without relevance to these traditional problems.

Persistence of Vision and Afterimages

Between the short persistence of vision and the remembrance of a long-passed event, there is an intermediate situation, the afterimage, which requires consideration. In discussing afterimages, it will be useful to distinguish some phases of vision that normally follow an intense or prolonged stimulus. First, there is the "initial" (or primary, or original) "image" (or sensation, or impression, or perception, or response). Any combination of a term from the first and from the second of these groups may be used. The initial image is followed by a latent period during which nothing is seen and which may in turn be followed by a complex sequence of afterimages. Afterimages may be either positive or negative; almost any sequence is possible, but the initial image is almost always positive.[15] Some authors distinguish the initial image from a positive afterimage (for example, McDougall, 1904); others do not (for example, von Helmholtz, 1924-25). It is often implicit in such distinctions that the persistence of the initial image is due to a continued excitatory process, whereas afterimages arise from receptor fatigue. If there is no repeated waxing and waning of sensation, but merely a single rise and fall, one cannot distinguish two phases in the primary image, one corresponding to the "initial image" and the other to an identical "positive afterimage" of it.

Although it is difficult to prove that visual information is stored in the initial image, there can be no gainsaying that an afterimage may be a rich store of information. Positive or negative afterimages may carry many fine details, including details that were not visible at the time of stimulation (von Helmholtz, 1924-25). Afterimages generally last for at least several seconds, and following high energy stimulation they normally last for several minutes (Berry & Imus, 1935). The clarity of the details, of course, deteriorates with the passage of time. Since afterimages appear to move when the eye is moved, they usually have been considered retinal phenomena. Taken together, these facts imply that *there is a considerable capacity for visual information storage in the retina.* If the illumination of the stimulus cards used in the foregoing experiments had been sufficiently intense to blaze the letters upon the retina and thereby take maximum advantage of its information storage capacity, there would have been little doubt afterwards as to the nature or location of most of the available information. The stimulus presentations actually used, however, rarely elicited reports of afterimages; *S*s usually reported seeing simply a single brief flash. The problem is therefore to determine the per-

[15] Bidwell (1897) and Sperling (1960) describe conditions for seeing a negative "after-image without prior positive image." The method involves a presentation quite similar to that of Baxt (1871).

sistence of the image of the brief flash, or equivalently, the duration of seeing (the stimulus) or the persistence of vision (of the stimulus), rather than the duration of an afterimage. These terms are used to suggest that the *S* feels he is responding directly to the stimulus rather than to aftereffects of stimulation.

Psychologists have often carelessly assumed that the absence of discernible afterimages following a visual presentation was sufficient to insure that the duration of sensation will correspond to the duration of the physical stimulus, that is, that there is no persistence of vision at all. Wundt (1899) was one of the first to take vigorous exception to this naive view. Wundt's most compelling example was drawn from Weyer (1899). Weyer had found that two 40-microsecond light flashes had to be separated by 40 to 50 msec. in order for them to be seen as two distinct flashes; at smaller separations they were seen as a single flash. In the dark adapted eye, the minimum separable interval that consistently yielded reports of "two flashes" was 80 to 100 msec.

Wundt argued that the two flashes could not be seen as distinct until the sensation occasioned by the first flash had ceased. Thus, under optimum conditions, the minimum duration of the sensation of a short flash was at least 40 msec. which, in this case, was 1,000 times the stimulus duration. Wundt thought that, in order to determine the duration of a longer flash, one must merely add the 40 msec. of fade-out time to the actual physical light duration. While these details of Wundt's reasoning may be questioned, his main point, based on the example of the short flash, is indisputable: one does not directly control the time for which information is visually available simply by manipulating exposure duration. The experiments reported here provide a direct proof of this assertion.

An Application of the Results to "Before and After" Experiments

The previous experiments showed that more information is available to *S*s for a few tenths of a second after the exposure than they can give in a complete report of what they have seen. It was suggested that the limit on the number of items in the memory report is a very general one, the span of immediate-memory, which is relatively independent of the nature of the stimulus. Evidence was offered that information in excess of the immediate-memory span is available to the *S* as a rapidly fading visual image of the stimulus. If more information is available to him than he can remember, the *S* must "choose" a part of it to remember. In doing so, he has chosen the part to forget. In Experiments 3 and 4, *S*s exercised only locational choices, that is, portions of the stimulus were remembered only on the basis of their location. Locational choices are probably not the only effective choices that the *S* can make. During the short time that information is available to him, the *S* may process it in any way in which he normally handles information. Usually, what he does, or attempts to do, is determined by the instructions. The *S*'s (unobservable) response to the stimulus is probably the same whether the instruction to make this response is given before the stimulus presentation or after it; the difference between the two cases lies in the information that the response can draw upon. If the stimulus contains more information than the *S*'s immediate-memory span, and if the post-exposure instruction is delayed until the *S* has little of this extra information available, then a difference in the accuracy of the responses with prior- and post-exposure instructions will be observed. If the stimulus does not contain more information than can be coded for immediate-memory, or if the post-exposure instruction is given soon enough so that the *S* can utilize the still available information effectively, then only minor differences in the accuracy of responses with prior- and post-exposure instructions will be observed. If the stimulus is destitute of information (for example, a single, mutilated, dimly illuminated letter of the alphabet) then a host of other factors which are normally insignificant may become crucial. In this case, the "stimulus" itself may well be irrelevant (Goldiamond, 1957), and the effects of instructions given before or after the exposure must be predicted on some other basis.

There are some simple experiments in which it is known a priori that the effects of instructions given either before or after the exposure will be exactly the same. This degenerate situation can be illustrated by a stimulus which is exposed for one microsecond and with sufficient energy to be clearly visible. By suitable coding, the pre-exposure and post-exposure instructions can be separated by only two microseconds. The example serves to emphasize that what is implicitly referred to by "before and after" is not the exposure but something else: traditionally, the sensitization and/or forgetting that presumably occur in conjunction with the exposure. Thus, the theory that has been presented here merely gives an explicit statement of assumptions that have long been implicit.

Unobservable Responses and the Order of Report

The subjective response to the high signal tone is "looking up." Since eye movements cannot occur in time to change the retinal image with any of the presentations used (Diefendorf & Dodge, 1908) a successful looking-up must be described in terms of a shift in "attention." Nonetheless, such a shift in attention can be quantitatively studied by means of a stabilized retinal image (Pritchard, 1958) although Wundt (1912), who did not use this modern, technically difficult technique, was able to give many essential details. The reaction time for the attentional response, like the reaction time for more observable responses, is greater than zero. Therefore, if the *S* is given an instruction before the presentation, he can prepare for, or sensitize himself to, the correct row of the stimulus even though there is not time enough for a useful eye movement. The response to an instruction which is given 0.05 sec. before the stimulus is probably the same as the response to a similar instruction that is given 0.1 sec. later, immediately after the exposure. The short time difference, 0.1 sec., accounts for the similar accuracy of responding in these two conditions.

Once his attention is directed to the appropriate row, the *S* still has to read the letters. This, too, takes time. Baxt's (1871) data indicate that the time required to read a letter is about 10 msec. Baxt's experiment, with some modifications, was repeated by the author, and similar results were obtained.[16]

How is all this relevant to the order of report? The order in which the letters are finally reported can be an important variable because of (*a*) purely temporal factors (letters that are reported first will be more accurately reported only because they are reported sooner after the exposure, the actual order of reporting the letters per se being relatively unimportant) or (*b*) interaction effects (the report of some letters is detrimental to the report of the remaining letters, that is, letters reported later suffer from proactive interference by the letters reported earlier).

That purely temporal factors cannot be very important can be seen from the slope of the curves describing available information as a function of time. In the foregoing experiments, the amount of available information approached the immediate-memory span at about 0.5 to 1.0 sec. after the exposure; further decrements in available information as a function of time are slight. The report of the letters usually does not begin until 1.0–1.5 sec. after the exposure. The passage of time during the actual time that letters are being reported, therefore, cannot account for appreciable accuracy changes as a function of the order of report.

The second possible effect of order of report—the interfering effect of the letters reported first upon unreported letters—cannot be so readily discounted. Proactive interference would imply that partial reports are more accurate than whole reports by an amount dependent upon their relative lengths. The results of Experiment 4 tend to support this view. At delays of the in-

[16] Sperling, G. Unpublished experiments conducted at the Bell Telephone Laboratories, 1958.

struction signal greater than 0.3 sec., partial reports of three letters (from stimuli of nine letters) indicate more available letters than do partial reports of four letters (from stimuli of twelve letters). On the other hand, in Experiment 7 one *S*, ROR, does not show decreased accuracy as a function of the length of his report. ROR is able to report eight letters as accurately when he begins his report with three or four incorrect letters as when he ends his report with three or four incorrect letters. Other *S*s did not systematically attempt to report incorrect letters first. Had they been required to report incorrect letters first, they might well have been able to do so.

The choice of what part of the stimulus to attend to or of which letters to read is the choice of what fraction of the stimulus information to utilize. This choice can be made successfully only while the information is still available. The *S*s prefer to report what they remember first, but this does not imply that they remember it because they report it first. It is difficult to disentangle the many factors that determine precisely what stimulus letters will appear in the response, but important choices of what information is to be recalled must occur while there is still something to choose from. Since the actual report begins only when there are available but a few letters in excess of the immediate-memory span, the order of report can at most play only the minor role of determining which of the few "excess" letters will be forgotten.[17]

The Questions of Generality and Repeatability

To what extent are the results obtained limited to the particular conditions of the foregoing experiments? The possibility that the actual physical fading of the light source is important to the availability of information can be rejected not only on prior grounds (see *Apparatus*) but also by the empirical findings. For example, in Fig. 9, the curve representing the number of letters available 0.15 sec. after exposure is quite similar to the 0.0-sec. delay curve. There is no visible energy emitted by the light source 0.15 sec. after its termination.

In the present case, the answer to the problem of repeatability of the results is made less speculative by three separate investigations that have since been conducted with similar techniques to those reported here.

The experiments have been repeated by the author[18] with a different tachistoscope, timer, and a light source that has only a negligible afterglow. All the main findings were reproducible.

Klemmer and Loftus (1958) confirmed the existence of a short-term, high information storage. They used a display consisting of four discrete line patterns, the *S* being required to report only one of these. The instruction was coded either as a signal light or verbally. Decay curves obtained when the instruction is delayed are similar to those reported above. A similar experiment has also been conducted by Averbach,[19] who used a television tachistoscope to present stimuli containing up to 16 letters. A pointer appeared above the letter to be reported. Initially, *S*s had about twelve letters available for report, but the number decreased rapidly when the visual instruction was delayed.

It is usually technically more difficult to code instructions visually than acoustically. Although the principle of sampling in order to determine available information is common to both kinds of instructions, visually coded instructions differ in some interesting ways from acoustically coded instructions. For example, the time taken to "interpret" —or even to find—a visual instruction may well depend on its location relative to the fixation point. Moreover, there may be

[17] There are many ways in which proactive interference might occur. For example, if letters are stored "sequentially" prior to report (cf. Broadbent, 1957b), then the importance of order of report may lie in the agreement of the two sequences: storage and report.

[18] Sperling, G. Unpublished experiments conducted at the Bell Telephone Laboratories, 1958.

[19] Averbach, E. Unpublished experiments conducted at the Bell Telephone Laboratories, 1959.

spatial interactions between the visual "instruction" and the symbols to be reported. On the other hand, prior to training, the task of interpreting a visual marker is easier for *S*s than the equivalent task with an acoustically coded instruction. Ultimately, such differences are probably only of secondary importance since the two kinds of experiments agree quite well.

Three main findings emerge from the experiments reported here: a large amount of information becomes available to observers of a brief visual presentation, this information decays rapidly, the final level is approximately equal to the span of immediate-memory. Although the exact, quantitative aspects of information that becomes available following a brief exposure unquestionably depend upon the precise conditions of presentation, it seems fair to conclude that the main results can be duplicated even under vastly different circumstances in different laboratories.

Summary and Conclusions

When stimuli consisting of a number of items are shown briefly to an observer, only a limited number of the items can be correctly reported. This number defines the so-called "span of immediate-memory." The fact that observers commonly assert that they can *see* more than they can *report* suggests that memory sets a limit on a process that is otherwise rich in available information. In the present studies, a sampling procedure (partial report) was used to circumvent the limitation imposed by immediate-memory and thereby to show that at the time of exposure, and for a few tenths of a second thereafter, observers have two or three times as much information available as they can later report. The availability of this information declines rapidly, and within one second after the exposure the available information no longer exceeds the memory span.

Short-term information storage has been tentatively identified with the persistence of sensation that generally follows any brief, intense stimulation. In this case, the persistence is that of a rapidly fading, visual image of the stimulus. Evidence in support of this hypothesis of visual information storage was found in introspective accounts, in the type of dependence of the accuracy of partial reports upon the visual stimulation, and in an analysis of certain response characteristics. These and related problems were explored in a series of seven experiments.

An attempt was first made to show that the span of immediate-memory remains relatively invariant under a wide range of conditions. Five practiced observers were shown stimuli consisting of arrays of symbols that varied in number, arrangement, and composition (letters alone, or letters and numbers together). It was found (Experiments 1 and 2) that each observer was able to report only a limited number of symbols (for example, letters) correctly. For exposure durations from 15 to 500 msec., the average was slightly over four letters; stimuli having four or fewer letters were reported correctly nearly 100% of the time.

In order to circumvent the immediate-memory limit on the (whole) report of what has been seen, observers were required to report only a part—designated by location—of stimuli exposed for 50 msec. (partial report). The part to be reported, usually one out of three rows of letters, was small enough (three to four letters) to lie within the memory span. A tonal signal (high, middle, or low frequency) was used to indicate which of the rows was to be reported. The *S* did not know which signal to expect, and the indicator signal was not given until after the visual stimulus had been turned off. In this manner, the information available to the *S* was sampled immediately after termination of the stimulus.

Each observer, for each material tested (6, 8, 9, 12 symbols), gave partial reports that were more accurate than whole reports for the same material. For example, following the exposure of stimuli consisting of 12 symbols, 76% of the letters called for in the partial report were given correctly by the observers. This accuracy indicates that the total information available from which an observer can draw his partial report is

about 9.1 letters (76% of 12 letters). This number of randomly chosen letters is equivalent to 40.6 bits of information, which is considerably more information than previous experimental estimates have suggested can become available in a brief exposure. Furthermore, it seems probable that the 40-bit information capacity observed in these experiments was limited by the small amount of information in the stimuli rather than by a capacity of the observers.

In order to determine how the available information decreases with time, the instruction signal, which indicated the row of the stimulus to be reported, was delayed by various amounts, up to 1.0 sec. (Experiment 4). The accuracy of the partial report was shown to be a sharply decreasing function of the delay in the instruction signal. Since, at a delay of 1.0 sec., the accuracy of the partial reports approached that of the whole reports, it follows that the information in excess of the immediate-memory span is available for less than a second. In contrast to the partial report, the accuracy of the whole report is not a function of the time at which the signal to report is given (Experiment 7).

The large amount of information in excess of the immediate-memory span, and the short time during which this information is available, suggests that it may be stored as a persistence of the sensation resulting from the visual stimulus. In order to explore further this possibility of visual information storage, some parameters of visual stimulation were studied. A decrease of the exposure duration from 50 to 15 msec. did not substantially affect the accuracy of partial reports (Experiment 5). On the other hand, the substitution of a white post-exposure field for the dark field ordinarily used greatly reduced the accuracy of both partial and whole reports. The ability of a homogeneous visual stimulus to affect the available information is evidence that the process depends on a persisting visual image of the stimulus.

Whether other kinds of partial reports give similar estimates of the amount of available information was examined by asking observers to report by category rather than by location. The observer reported numbers only (or the letters only) from stimuli consisting of both letters and numbers (Experiment 6). These partial reports were no more accurate than (whole) reports of all the letters and numbers. The ability of observers to give highly accurate partial reports of letters designated by location (Experiment 3), and their inability to give partial reports of comparable accuracy when the symbols to be reported are designated as either letters or numbers, clearly indicates that all kinds of partial reports are not equally suitable for demonstrating the ability of observers to retain large amounts of information for short time periods.

In the final study (Experiment 7), the order of report was systematically varied. Observers were instructed to get as many letters correct as possible, but the order in which they were to report the letters was not indicated until after the exposure. An instruction tone, following the exposure, indicated which of the two rows of letters on the stimulus was to be reported first. This interference with the normal order of report reduced only slightly the total number of letters that were reported correctly. As might be expected, the first row—the row indicated by the instruction tone—was reported more accurately than the second row (order effect). There was, however, a strong tendency for the top row to be reported more accurately than the bottom row (position effect). Although, as a group, the observers showed both effects, some failed to show either the order or the position effect, or both. The fact that, for some observers, order and position are not correlated with response accuracy suggests that order of report, and position, are not the major *causes* of, nor the necessary conditions for, response accuracy. The high accuracy of partial report observed in the experiments does not depend on the order of report or on the position of letters on the stimulus, but rather it is shown to depend on the ability of the observer to read a visual image that persists for a fraction of a second after the stimulus has been turned off.

REFERENCES

ADAMS, J. S. The relative effectiveness of pre- and post-stimulus setting as a function of stimulus uncertainty. Unpublished master's dissertation, Department of Psychology, University of North Carolina, 1955.

ALPERN, M. Metacontrast. *J. Opt. Soc. Amer.*, 1953, **43**, 648–657.

BAXT, N. Über die Zeit welche nötig ist damit ein Gesichtseindruck zum Bewusstsein kommt und über die Grösse (Extension) der bewussten Wahrnehmung bei einem Gesichtseindrucke von gegebener Dauer. *Pflüger's Arch. ges. Physiol.*, 1871, **4**, 325–336.

BERRY, W., & IMUS, H. Quantitative aspects of the flight of colors. *Amer. J. Psychol.*, 1935, **47**, 449–457.

BIDWELL, S. On the negative after-images following brief retinal excitation. *Proc. Roy. Soc. Lond.*, 1897, **61**, 268–271.

BRIDGIN, R. L. A tachistoscopic study of the differentiation of perception. *Psychol. Monogr.*, 1933, **44**(1, Whole No. 197), 153–166.

BROADBENT, D. E. Immediate memory and simultaneous stimuli. *Quart. J. exp. Psychol.*, 1957, **9**, 1–11. (a)

BROADBENT, D. E. A mechanical model for human attention and memory. *Psychol. Rev.*, 1957, **64**, 205–215. (b)

BROADBENT, D. E. *Perception and communication.* New York: Pergamon, 1958.

CATTELL, J. McK. Über die Trägheit der Netzhaut und des Sehcentrums. *Phil. Stud.*, 1883, **3**, 94–127.

CHAPMAN, D. W. The comparative effects of determinate and indeterminate aufgaben. Unpublished doctor's dissertation, Harvard University, 1930.

CHAPMAN, D. W. Relative effects of determinate and indeterminate "Aufgaben." *Amer. J. Psychol.*, 1932, **44**, 163–174.

COHEN, L. D., & THOMAS, D. R. Decision and motor components of reaction time as a function of anxiety level and task complexity. *Amer. Psychologist*, 1957, **12**, 420. (Abstract).

DALLENBACH, K. M. Attributive vs. cognitive clearness. *J. exp. Psychol.*, 1920, **3**, 183–230.

DIEFENDORF, A. R., & DODGE, R. An experimental study of the ocular reactions of the insane from photographic records. *Brain*, 1908, **31**, 451–489.

DODGE, R. An experimental study of visual fixation. *Psychol. Monogr.*, 1907, **8**(4, Whole No. 35). (a)

DODGE, R. An improved exposure apparatus. *Psychol. Bull.*, 1907, **4**, 10–13. (b)

ERDMANN, B., & DODGE, R. *Psychologische Untersuchungen über das Lesen auf experimenteller Grundlage.* Halle: Niemeyer, 1898.

GLANVILLE, A. D., & DALLENBACH, K. M. The range of attention. *Amer. J. Psychol.*, 1929, **41**, 207–236.

GOLDIAMOND, I. Operant analysis of perceptual behavior. Paper read at Symposium on Experimental Analysis of Behavior, APA Annual Convention, 1957.

JAMES, W. *The principles of psychology.* New York: Holt, 1890.

KLEMMER, E. T. Simple reaction time as a function of time uncertainty. *J. exp. Psychol.*, 1957, **54**, 195–200.

KLEMMER, E. T., & LOFTUS, J. P. *Numerals, nonsense forms, and information.* USAF Cambridge Research Center, Operational Applications Laboratory, Bolling Air Force Base, 1958. (Astia Doc. No. AD110063)

KÜLPE, O. Versuche über Abstraktion. In, *Bericht über den erste Kongress für experimentelle Psychologie.* Leipzig: Barth, 1904. Pp. 56–68.

LADD, G. T. *Elements of physiological psychology: A treatise of the activities and nature of the mind.* New York: Scribner, ~~1889~~. 1887

LAWRENCE, D. H., & COLES, G. R. Accuracy of recognition with alternatives before and after the stimulus. *J. exp. Psychol.*, 1954, **47**, 208–214.

LAWRENCE, D. H., & LABERGE, D. L. Relationship between accuracy and order of reporting stimulus dimensions. *J. exp. Psychol.*, 1956, **51**, 12–18.

LINDSLEY, D. B., & EMMONS, W. H. Perception time and evoked potentials. *Science*, 1958, **127**, 1061.

LONG, E. R., HENNEMAN, R. H., & REID, L. S. Theoretical considerations and exploratory investigation of "set" as response restriction: The first of a series of reports on "set" as a determiner of perceptual responses. *USAF WADC tech. Rep.*, 1953, No. 53–311.

LONG, E. R., & LEE, W. A. The influence of specific stimulus cuing on location responses: The third of a series of reports on "set" as a determiner of perceptual responses. *USAF WADC tech. Rep.*, 1953, No. 53–314. (a)

LONG, E. R., & LEE, W. A. The role of spatial cuing as a response-limiter for location responses: The second of a series of reports on "set" as a determiner of perceptual responses. *USAF WADC tech. Rep.*, 1953, No. 53–312. (b)

LONG, E. R., REID, L. D., & GARVEY, W. D. The role of stimulus ambiguity and degree of response restriction in the recognition of distorted letter patterns: The fourth of a series of reports on "set" as a determiner of perceptual responses. *USAF WADC tech. Rep.*, 1954, No. 54-147.

LUCE, D. R. *A survey of the theory of selective information and some of its behavioral applications.* New York: Bureau of Applied Social Research, 1956.

McDougall, W. The sensations excited by a single momentary stimulation of the eye. *Brit. J. Psychol.*, 1904, **1**, 78–113.

Miller, G. A. Human memory and the storage of information. *IRE Trans. Information Theory*, 1956, **IT-2**, No. 3, 129–137. (a)

Miller, G. A. The magic number seven, plus or minus two: Some limit on our capacity for processing information. *Psychol. Rev.*, 1956, **63**, 81–97. (b)

Miller, G. A., & Nicely, P. E. An analysis of perceptual confusions among some English consonants. *J. Acoust. Soc. Amer.*, 1955, **27**, 338–352.

Piéron, H. L'évanouissement de la sensation lumineuse: Persistance indifferenciable et persistance totale. *Ann. psychol.*, 1934, **35**, 1–49.

Pollack, I. The assimilation of sequentially-encoded information. *Hum. Resources Res. Lab. memo Rep.*, 1952, No. 25.

Pritchard, R. M. Visual illusions viewed as stabilized retinal images. *Quart. J. exp. Psychol.*, 1958, **10**, 77–81.

Quastler, H. Studies of human channel capacity. In H. Quastler, *Three survey papers.* Urbana, Ill.: Control Systems Laboratory, Univer. Illinois, 1956. Pp. 13–33.

Schumann, F. Die Erkennung von Buchstaben und Worten bei momentaner Beleuchtigung. In, *Bericht über den erste Kongress für experimentelle Psychologie.* Leipzig: Barth, 1904. Pp. 34–40.

Schumann, F. The Erkennungsurteil. *Z. Psychol.*, 1922, **88**, 205–224.

Sperling, G. Information available in a brief visual presentation. Unpublished doctor's dissertation, Department of Psychology, Harvard University, 1959.

Sperling, G. Afterimage without prior image. *Science*, 1960, **131**, 1613–1614.

von Helmholtz, H. *Treatise on physiological optics.* Vol. II. *The sensations of vision.* (Transl. from 3rd German ed.) Rochester, New York: Optical Society of America, 1924–25.

Wagner, J. Experimentelle Beitrage zur Psychologie des Lesens. *Z. Psychol.*, 1918, **80**, 1–75.

Weyer, E. M. The Zeitschwellen gleichartiger und disparater Sinneseindrucke. *Phil. Stud.*, 1899, **15**, 68–138.

Whipple, G. M. *Manual of physical and mental tests.* Vol. I. *Simpler processes.* Baltimore: Warwick & York, 1914.

Wilcocks, R. W. An examination of Külpe's experiments on abstraction. *Amer. J. Psychol.*, 1925, **36**, 324–340.

Woodworth, R. S. *Experimental psychology.* New York: Holt, 1938.

Wundt, W. Zur Kritik tachistosckopischer Versuche. *Phil. Stud.* 1899, **15**, 287–317.

Wundt, W. *An introduction to psychology.* London: Allen & Unwin, 1912.

(Early publication received April 28, 1960.)