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Measuring the Reaction Time of A Shift of Visual Attention*

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ABSTRACT

The reaction time for shifting attention from a target letter at the left of fixation to a stream of numerals at the right of fixation is measured by noting the earliest-occurring numeral an observer can report. In addition to this attention reaction time (ART), the observer produces a conventional motor reaction time (MRT) by indicating target detection with a finger movement. ARTs and MRTs have comparable distributions over trials, but ARTs vary more with the difficulty of targets than do MRTs to the same targets. The results are accounted for by a two-stage three-component model of reaction times consisting of a shared *detection* component (in which detection for attention responses requires 50% longer processing than detection for motor responses) followed by independent attention and motor response-generating components. A *mental snapshot* model is proposed to account for the functioning of the attention response-component.

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INTRODUCTION

As any party goer or student can testify, it is possible to look fixedly at one thing while paying attention to another. Psychologists, too, have long believed that one's visual attention can be shifted from one object to another with no discernable outward sign such as a change in eye position (Helmholtz, 1924, p. 455; James, 1890, p. 437; Wundt, 1924, p. 20). The experimental procedure described here is an objective method for measuring such a covert shift in visual attention.

PROCEDURE

Outline. A subject is instructed to maintain steady eye fixation on a fixation dot shown on a cathode-ray oscilloscope. To the left of the fixation dot a steady stream of letters appears; to the right is a steady stream of numerals. The letters appear one after the other, in the same location, at a rate of 4.6 letters per second. The subject's task is to detect a target in the letter stream and then, without moving his eyes from the dot, to report the earliest possible numeral from the numeral stream—preferably the numeral that occurred simultaneously with the target.

In our experiments, the target was any one of the three symbols: the letters U or C or an outline square. It was presented at a randomly determined location in the letter stream between the ninth and the twentieth letters. The numerals appeared, in various conditions, at rates of 4.6, 6.9, 9.1, or 13.4 per second. The stimulus conditions are designed so that subjects report they have to give "full attention" to the letter stream in order to detect the targets reliably, and they have to "shift attention" to report the numeral. In fact, subjects seldom succeeded in reporting the simultaneous numeral, and they actually reported a numeral that occurred later. The time delay between the target letter on the left and the reported numeral on the right defines an attention reaction time (ART): The earlier in the sequence is the reported numeral, the quicker is the inferred ART. From a series of trials, we can obtain an entire distribution of ARTs.

Stimuli. The stimuli were composed of vectors generated by a Digital Equipment Corp. PDP/15 computer on an oscilloscope with a fast P4 phosphor. Stimuli were viewed binocularly at a distance of 0.69 m. The height of the letters and numbers was 1.75 cm (1.45 deg) and they were separated (center to center) by 2.25 cm (1.87 deg). Characters were refreshed three times during a display period of 3.6 msec. The screen was blank between characters. The total luminous energy per character varied from 1.92×10^{-6} cd-sec for *I* to $3.33\ 10^{-6}$ cd-sec for W. Background luminance of the display was $0.10\ \text{cd}/\text{m}^2$

for subject AR, and the room illumination was approximately 0.9 m-cd. For the other two subjects, these figures were, respectively, 0.35 cd/ m^2 and 0.5 m-cd. See Sperling (1971) for calibration methods.

Eye Position. Objective measurements of eye position showed that subjects did indeed maintain fixation as instructed. (1) One subject's eye movements were measured by an electro-oculogram method whose sensitivity was determined to be amply sufficient to detect a movement from the fixation dot to either of the character streams. In several sessions that yielded typical data, such eye movements did not occur. (2) A saccadic eye movement made during viewing of the displays frequently causes the apearance of multiple images of the display. In the early practice sessions, subjects quickly learned to suppress eye movements to avoid these multiple images.

Motor Reaction Time, Critical Interval. On each trial, in addition to reporting the numeral, the subject also had to make a more traditional response to each appearance of the target: He had to lift his finger from a key as soon as he detected the target. The set of motor reaction times (MRTs) for the finger response serves as a standard of comparison for the covert attention response in which we were primarily interested. The motor reaction time includes the time of many component processes (e.g., detection of the target, response selection, muscle contraction, and finally, sufficient movement of the finger to activate the response key). As we shall show later, the components of an attention reaction time include some processes shared in common with the motor reaction and others that are particular to the numeral selection task. By analogy to the MRT, the ART refers not merely to a single component but to all the component processes that intervene between the occurrence of a target and the response (finger movement or numeral selection) being measured.

As in traditional reaction-time experiments, the subject was instructed to make the motor response (lifting his finger from the key) as quickly as possible (i.e., as early as possible in an interval immediately following the onset of the target stimulus, called the *critical interval*). The reaction-key response terminated the display after 1 sec. In reaction-time experiments, when a subject responds too soon or too late, he is admonished to be more careful; those responses are assumed to be false and are discarded. Based on preliminary experiments, we defined the critical interval as 170 to 1700 msec after the target onset. When a response occurred outside the critical interval, the subject was so informed, and the trial was omitted from the data analysis. Overall, this occurred on 1.6% of the trials. As subjects became more experienced, it became obvious that the critical interval was overly generous—it could have been shortened to less than 1 sec without substantially altering the fraction of rejected data.

Attention Reaction Times, Critical Sets. In measuring the attention reaction times, the *critical interval* is replaced by a *critical set* of numerals in the numeral stream. Usually, the critical set was defined as the seven consecutive numerals that begin with the first numeral occurring subsequent to the target. However, the position of the critical set was adjusted somewhat with conditions to ensure that it did not limit the subject's performance. For example, with very slow numeral rates, when the subject could occasionally report the numeral simultaneous with the target, the critical set included the numerals in the zero position (simultaneous) and in the -1 position.

On every trial, the seven numerals of the critical set, plus the two preceding and the one following, always comprised a sequence of 10 all-different numerals. The subject was instructed to detect the target letter and then to report the earliest-seen numeral in the critical set of numerals. He typed his response on a keyboard in front of him and immediately received feedback in the form of a display of the critical set. If a numeral had been typed in that was not in the critical set, the word *WRONG* was displayed. Overall, this occurred 3% of the time.

RESULTS

MRTs and ARTs

Typical Results. The procedure and some typical data are summarized in Fig. 17.1. The columns on the left side show a sample of a typical stimulus sequence. The fixation point was always present. A new letter appeared every 218 msec in the letter stream, and (in this example) a new numeral, every 109 msec in the numeral stream. The target here was the letter C. The numeral that appeared at the same time as the target—in this case a 6—is defined as being in position 0; the critical set consists of the numerals in positions 1 through 7.

Sample responses are shown in the middle columns of Fig. 17.1. For the attention-shift response, the subject typed in the numeral 9 (the third numeral in the critical set). The motor response occurred with an RT of about 400 msec.

The graphs on the right side of Fig. 17.1 show actual data of one subject for this condition. The graph of attention reaction time (ART) shows the proportion of times the subject responded with numerals in each position of the critical set. The numeral in the +3 position was the most frequently made response. The mean ART occurred 457 msec after the target; the standard deviation was 79 msec. The graph of motor reaction time (MRT) shows the distribution of latencies for the finger-lifting response. The mean of this distribution was 436 msec; the standard deviation, 73 msec. In this example, the mean ART is slower than the mean MRT; however, ARTs can be either faster or slower than the MRTs, depending on the conditions and the subjects.

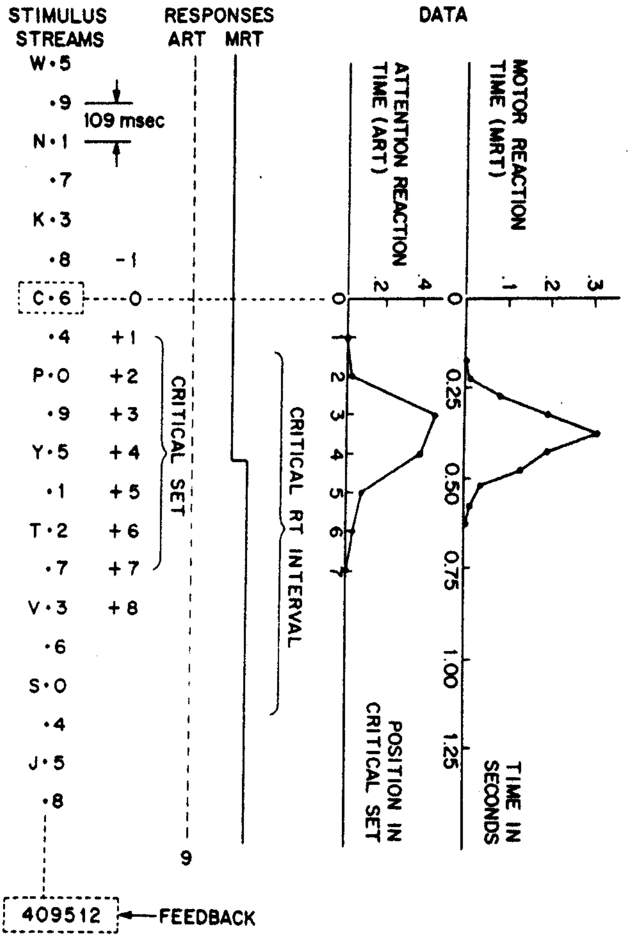

FIG. 17.1. Procedures and typical results of the ART and MRT measurements. Stimulus streams are shown at left. The subject sees only the letters, the fixation dots, and the numerals. Each row represents a single display, briefly flashed and superimposed on the preceding display. The target letter is a C. The critical set of numerals and the critical reaction-time periods are indicated. MRT indicates the finger (motor) reaction-time key, and ART indicates the attention-shift reaction "9". Feedback indicates the answer display (first six numerals of critical set) shown to the subject after his ART response. The results show the actual observed MRT distribution and the observed ART distribution (proportion of times a numeral corresponding to each position is named) for 414 trials in this particular condition: letter stream rate 4.6 per second, target C, numeral rate 9.1 per second, recall of one letter, subject AR.

Statistical Problems in the Treatment of ART Responses

The MRT distribution is a complete probability distribution and all moments can be estimated directly from the data by conventional statistics. The ART distribution is not complete because a nonnegligible number of ARTs occur outside the critical set, typically 1-5%. To estimate the ART moments, we find the Gaussian density function over the whole numeral sequence that best fits the ART distribution (in a least-squares sense) within the critical set and that predicts the observed number of reports outside the critical set. We use the moments of this Gaussian as estimates of the ART moments. The estimation method is most sensitive to the central part of the distribution and relatively insensitive to the tails, where our data are incomplete. Although we offer no proof that this unusual Gaussian fitting procedure has desirable properties in general, it is easy to demonstrate its good properties in a case very similar to the ART distributions, namely, the MRT distributions. By applying the Gaussian fitting procedure to the MRT distributions for which true sample means are available, we can compare the Gaussian estimates of the means with the true sample means. The Gaussian procedure gives estimates of the MRT means that differ absolutely from the true sample means by less than 1 msec (.5%) on the average—very good agreement, indeed. The fit of the Gaussian distribution was tested with the Kolgomorov-Smirnov D statistic and was rejected ($p < .05$) for only 8 of the 59 observed ART distributions.

Another complication is that the lateral position (but not the shape) of the ART distribution depends somewhat on the assumptions made. It is assumed here that, after an attention shift occurs, the subject reports the most recently presented numeral. For example, if numerals occur every 109 msec, and if the subject shifts attention from the target to the numerals in less than 109 msec, then he would report the numeral that occurred simultaneously with the target. For more details, see Reeves (1977).

Subjects' Knowledge of Position; Order Information

We wondered why three highly motivated, well-practiced subjects—each extensively trained before the start of the experiments and then serving in 17 experimental sessions for a total of almost 5000 trials with full feedback—were not able to name earlier-occurring numerals. Why could they not, for example, pay partial attention to the numeral stream, remember the order of the numerals, and give a response based on reconstruction from this memory? In an attempt to answer this question, two different procedures were used.

Position Judgments. In the first procedure, subjects were asked to estimate the position within the critical set of the numeral they reported (i.e., to say whether it occurred *early*, *middle*, or *late* in the critical set). We found that, with slow numeral rates, the subjects quickly learned to judge whether the first numeral they could report occurred early or late in the numeral stream. But at the fastest numeral rates, subjects were unable to estimate reliably the position of their response numeral, even after much practice. For one subject, the ART distribution for responses designated as *early* coincided exactly with the distribution for responses designated as *late*. Evidently, at the fastest rates, the subjects have little or no order information available to them—they do not know the actual temporal order of the numerals.

Recall-4 Procedure. This conclusion was further supported by the results of our second procedure, "Recall-4." Subjects were instructed to report not only the earliest numeral they could in the critical set but also the next three numerals. Although complete analysis of these Recall-4 data is more complex than of the single response data (Recall-1), the results of the analysis (Reeves, 1977) are unambiguous: at the slower numeral rates the subjects succeeded quite well at the task. At the fastest numeral rates, their responses showed no evidence of order information.[1]

Covariation of MRT, ART

Target Difficulty. The motor reaction time (MRT) depends on which target occurs. Mean MRT is slowest for U and quickest for the square. These MRTs are consistent with the ease of detection of these targets against the letter background. To create the easiest possible detection task, in another experiment, the background letters were eliminated and the target was simply an arrow pointing at the numeral stream. This arrow condition gave the fastest MRTs. The order of mean *attention* reaction times (ARTs) to the four kinds of targets corresponded within measurement error to the order of the MRTs. These data, illustrated in Fig. 17.2, show that targets that slow the ART also slow the MRT, though to a lesser extent.

Numeral Rate. Insofar as both MRTs and ARTs depend only on target processing, numeral rate should have no effect on them. In fact, numeral rate has a small effect on MRTs (MRTs are slow at slow numeral rates) and a large effect in the opposite direction on ARTs. However, an analysis of variance shows that there is no significant interaction between the main effects (upon MRT or ART) of target difficulty and of numeral rate: These factors work independently (i.e., the curves of Fig. 17.2 are approximately parallel). The effect of numeral rate upon the ART is analogous to the effect upon the MRT

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[1] When Ss listen to repeated sequences of *unfamiliar* sound, they are absolutely unable to report correctly the order of these sounds even when the duration of individual sounds is long enough to permit the easy discrimination of the order in sequences composed of familiar speech sounds (Warren, Obusek, Farmer, & Warren, 1969). Warren (1974) proposes that discrimination of order at high item rates requires the prior learning of overall patterns. At high visual presentation rates, the difficulty our subjects experienced in discriminating order is analogous to the difficulty Warren's subjects experienced with unfamiliar sounds. By analogy this would suggest that our subjects did not learn the overall patterns produced by consecutive visual numbers.

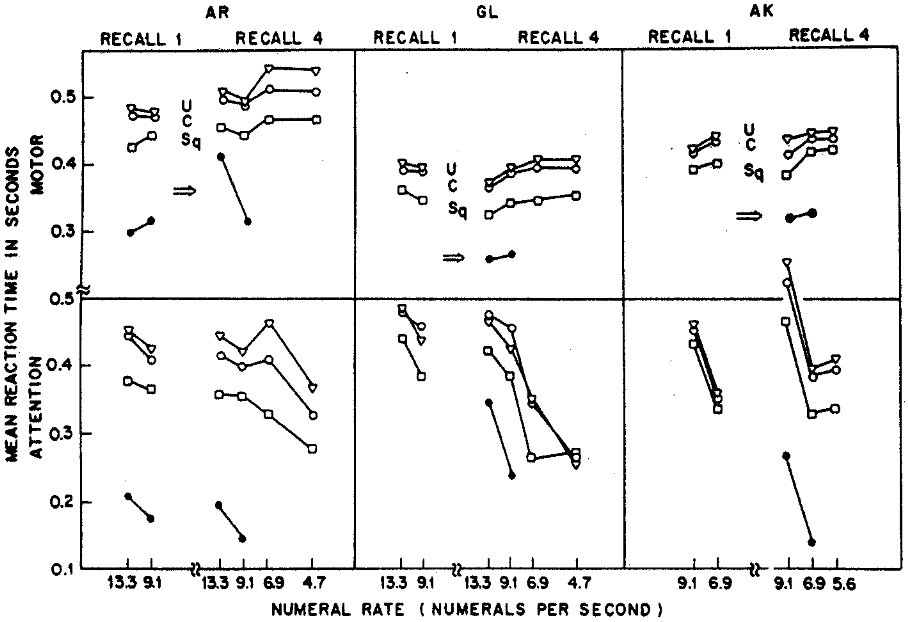

FIG. 17.2. Mean ART (left) and mean MRT (right) as a function of numeral rate (reciprocal of the time *T* from one of one numeral to the next). Target type is the parameter. Targets U (Δ), C (O), and Square (□) were run in a mixed list; the arrow condition was run separately. Data of three subjects are shown in both conditions, Recall-1 and Recall-4 (see text). The ARTs in the Recall-4 data are for the first numeral (of four) reported, and all ART means are computed by the method described in the text.

of changing the finger being used or the mechanical characteristics of the reaction key. Absolute RTs change but differences are preserved. Thus, fast and slow numeral rates give identical estimates of the *differences* in ARTs and in MRTs for the various targets.

Factor independence means, for example, that if ARTs are 40 msec longer for the U target than for the □ target, this same 40 msec difference will be found whether the ART is measured at fast or at slow numeral rates. Factor independence of target difficulty and of numeral rate upon the variance of MRT and ART also was tested and found to hold (see Reeves, 1977). Thus, the choice of numeral rate for an ART experiment is a matter of convenience. All conclusions about the relative speeds of processing different targets would be the same at all the numeral rates tested.

Foreperiod Effect. The foreperiod refers to the position of the target letter within the letter stream. *When* a target occurs (i.e., early or late) has a significant influence upon reaction time, presumably because late-occurring targets are more predictable (Nickerson, 1965, 1967; Nickerson & Burnham,1969; Snodgrass, 1969). Averaging ARTs and MRTs over all subjects and conditions, we find that RTs to targets in the last quartile(target positions 18, 19, 20) are 33 msec faster than RTs to stimuli in the earliest quartile(target positions 9, 10, 11); this decrease in reaction times is linear over quartiles. Averaging over subjects and conditions, the foreperiod effect is the same for ARTs and MRTs. Analysis of variance shows the foreperiod effect does not interact with the effect of target identity on ART or MRT (i.e., the two effects are additive). That foreperiod and target difficulty have a similar effect on ART and on MRT can be regarded as a further substantiation of the ART method. These two variables produce their expected effects on both MRT and ART.

Other Results

Numeral Identity. There is a small but statistically significant tendency for subjects to report the numeral 1 less often than the other numerals which, within measurement error, are reported equally often. There is no significant tendency for any numeral (including 1) to be reported earlier or later than any other. As far as we have been able to determine, ARTs are independent of which particular numerals happen to occupy the critical positions.

Subjects' Guessing Strategies. In other experiments, not reported here, in which the numeral stream was augmented to contain 16 characters (rather than just 10 numerals), characters from certain positions *never* appeared in the response. Because a random selection of characters would have produced characters from every position, the systematic absence of certain positions indicates there was no purely random guessing. Additionally, the data of the present experiments were subjected to various analyses by a procedure that corrects for sophisticated guessing strategies (Sperling & Melchner, 1976). The "corrected" and uncorrected data do not differ in any respects that are important for the issues under consideration.

THEORY

Two-Stage, Three-Component Model for MRT and ART

All the previous results and many others are encapsulated in a two-stage three-component model consisting of a detection-recognition component d that contributes both to the MRT and the ART; a motor component m that contributes only to the MRT; and an attention component a that contributes only to the ART. The model is distribution-free; each component contributes to a mean μ and a variance σ^2 to the observed reaction-time distribution.

MRTs. Let i represent a particular target and j, a numeral rate. The predicted means $\overline{\mathrm{MRT}}(i, j)$ and variances VAR[MRT(i, j)] of the MRT distributions are:

$$\overline{\mathrm{MRT}}(i, j) = \mu_d(i) + \mu_m \tag{1}$$

$$\mathrm{VAR}[\mathrm{MRT}\ (i, j)] = \sigma_d^2\ (i) + \sigma_m^2. \tag{2}$$

ARTs. To a first approximation, MRTs are independent of the various numeral rates, so we omit rate parameters in predicting them. ARTs, however, do depend strongly on the numeral rate and this must be incorporated in the prediction. Moreover, to account for the somewhat greater effect of target on ART than on MRT, the model assumes that processing of stimuli by the detection-recognition component takes longer for initating the attention response than for initiating the motor response, by a factor of $1 + h$, where $h > 0$. For concreteness, the detection-recognition process can be represented by a random walk, information-accumulation process (Laming, 1968; Link & Heath, 1975; Stone, 1960) with a lower threshold for initiating the motor response process than for initiating the attention response process. The predicted means $\overline{\mathrm{ART}}\ (i, j)$ and variances VAR[ART (i, j)] of the ART distributions are:

$$\overline{\mathrm{ART}}(i, j) = (1 + h)\ \mu_d(i) + \mu_a(j) \tag{3}$$

$$\mathrm{VAR}[\mathrm{ART}\ (i, j)] = (1 + h)\sigma_d^2\ (i) + \sigma_a^2(j). \tag{4}$$

In a given condition of target i and numeral rate j, the predicted covariance between MRT and ART, COV (MRT, ART$|i, j$), is simply

$$\mathrm{COV}(\mathrm{MRT},\ \mathrm{ART}|i, j) = \sigma_d^2 \tag{5}$$

Parameter Estimation. In any one condition (i, j), there are seven model parameters [(h, $\mu_d(i)$, $\sigma_d(i)$, $\mu_a(j)$, $\sigma_a(i)$, μ_m, σ_m] and only five observables. However, 18 conditions were conducted in a balanced design for each of subjects AR and GL and 15 conditions for AK. The 18 conditions yield 90 observable quantities and require only 17 model parameters so that parameter estimation is feasible in principle.

Predictions of means and of variances are separable in the model. The additive effects of target difficulty and of numeral rate on the predicted mean $\overline{\mathrm{ART}}$s and $\overline{\mathrm{MRT}}$s is essentially an embodiment of the finding of no significant interaction from an analysis of variance. It is not suprising, therefore, that predictions of the means are reasonably good, accounting for .69 to .88 of the variance to the observed means.

The model correctly predicts the linear regression [with slope $(1 + h)^{-1}$] of the $\overline{\mathrm{MRT}}$s upon the $\overline{\mathrm{ART}}$s between conditions (i.e., the way mean MRTs and mean ARTs vary together with different targets). This aspect of the predictions is incoporated in the parameter h; the average value of h for the three subjects was 0.51. This means that on the average there is a 51% greater effect of increasing target difficulty on ARTs than on MRTs. In the model, an h greater than zero means that a target initiates an attention response process only some time after it has already initiated a motor response process (i.e., the ART undergoes more processing in the detection component than the MRT).

Predictions. There are three important predictions from the variances in the model:

1. *The correlation, within conditions, between individual ARTs and MRTs elicited by the same stimulus.* This correlation is predicted to be positive (because it is proportional to the fraction of total response variance that is shared between ARTs and MRTs) and small (because the sharing is restricted to the first part of the joint detection stage). In the data, all these ART-MRT correlations were small and positive, as predicted.
2. *The slope of the MRT variances upon the ART variances.* At each numeral rate, for the various targets, the slope of the MRT variances upon the ART variances is predicted to be the same as the corresponding slope of the means $(1 + h)^{-1}$. This prediction assumes the variation in additional processing that the ART undergoes in the joint detection component is uncorrelated with the shared processing. [The slope would be predicted to be $(1 + h)^{-2}$ if the ARTs' additional detection processing were perfectly correlated with the shared processing. This would occur if the trial-to-trial variation in detection latency were due to stimulus variations, such as target context, rather than to internal fluctuations within the information-accumulation process.]
3. *Absolute estimation of variances.* The model enables absolute estimation individually of σ_d, σ_m, and σ_a. In contrast to previous MRT models, there is no arbitrary constant that can be exchanged between these quantities without producing an observable change in MRT (or ART) variances.

Unfortunately, none of these three predictions could be critically tested because meaningful estimation of model parameters from variances requires much greater precision of sample variances (relative to their own variability) than we had.

Mental Snapshot Model for ARTs

By considering a broader set of data that includes, in addition to the observables in Equations 1 and 2, the subjects' introspections and a comprehensive analysis of report order, we have arrived at a "mental snapshot" model of the attention component. The model represents activity in a higher-level visual short-term memory (VSTM) that simultaneously maintains representations of several successively presented stimuli (Scarborough, 1972; Sperling & Kaufman, 1978). We shall not dwell here on how these processes actually might be carried out in the brain but rather on the formal analogy to taking and examining a photograph.

The memory model assumes there is a representation of each of the numerals in a *visual processor.* Every time a particular numeral is viewed by the subject, a corresponding representation in this visual processor is activated. The representation remains active at least until the next numeral is displayed to the subject, when the new representation becomes active. As soon as a target is detected in the letter stream, the activity pattern in the processor begins to be registered in the visual short-term memory. Registration of activity is not instantaneous, however, but occurs during an interval of about .25 sec (during which several numerals become active.) Ultimately, numerals are reported in an order that corresponds to their total, cumulated activity during the registration interval.

The visual processor is analogous to a panel of numbers on which a number lights up whenever it is being presented. The VSTM system corresponds to a camera pointed at the panel. Target detection is analogous to triggering the camera to take a picture of the panel. The registration process corresponds to the camera shutter opening gradually and closing gradually, with a minimum exposure time of about .25 sec. Thus, several numerals may appear on the same piece of film, each exposed by different amounts depending on how wide open the shutter was during the time the numeral was illuminated. The photographic image on the film represents the contents of VSTM. The process by which a sequence of numerals is retrieved from VSTM corresponds to the following reporting strategy vis a vis the photograph: The most visible (most exposed) numeral is reported first. When more than one numeral is asked for, the second most visible is reported next, and so on. It follows that numerals that were partially exposed (i.e., numerals that were presented as the shutter was opening or when it was closing) will be reported in haphazard order after the numerals that were presented while the camera shutter was wide open.

Two Factors Determine Order of Report. Temporal order information in VSTM is hypothesized to consist of a radically different kind of information: a marker associated with each numeral indicating its time of occurrence in the snapshot independently of its strength. Useful markers are assumed to require more time for their formation than is available at the highest rates of numeral presentation, but markers become quite effective at low rates. Thus, there is a single factor (exposure strength) that determines order of report at high presentation rates, but there are two factors (strength and relative time of occurrence) that combine to determine the response sequence at low numeral rates. This two-factor model leads to a precise mathematical representation that provides accurate descriptions of the sequences of response numerals that subjects produced in the various Recall-4 conditions (Reeves & Sperling, 1977).

The model clarifies the answer to the problem of reconstructive memory. Where marker-type order information is lacking, as at high numeral rates, there is no possibility of effective reconstruction from memory; "working backward" in memory to retrieve earlier items could be attempted, but it would primarily increase the variance and not reliably alter the mean reported position. Therefore, at high rates, the ART distribution directly estimates the moment of maximal attention to the numerals (i.e., the moment of fastest registration—the moment at which the shutter is fully open).

Where there is marker-type order information, as at slow numeral rates, the subject can use the markers to partially reconstruct the actual order of the numerals in the critical set; the response numerals then come from the early phase of the attentional response. At low numeral rates there is the possibility of complication if there is partial attention to the numeral stream even during target search. In the mental snapshot model, partial attention corresponds to the shutter being left slightly open and the film being advanced from time to time. When events occur very slowly in the numeral stream, the order traces are better, the film needs to be advanced less often, and therefore it is easier to reconstruct the sequence backward from the time attention is shifted. Thus, in the case of a simple detection task (an "arrow" target when the background characters are blanks) and a slow numeral rate (4.6 per second), we find good order memory and evidence of continuous partial attention to the numerals. For example, subjects occasionally report the numeral from the -1 position. But these factors are easily manipulable. By choosing a detection task sufficiently difficult to require full attention to the letter stream and by choosing a sufficiently high rate of numeral presentation to minimize pointer-type order information, we obtain an ideal situation for measuring attention shifts, a situation corresponding to the "shortest exposure" of a mental snapshot.

To return again to the main results, we now interpret the decrease in mean ART with decreasing numeral rate as due to reconstructive memory at the slow rates. Because there is no interaction of numeral rate and target difficulty in the data or in the two-stage model, the choice of numeral rate for an ART experiment is a matter of convenience. As noted previously, any conclusion about the relative speeds of processing different targets would be the same at all the numeral rates tested.

Perceived Temporal Order

Finally, the present analysis has direct applicability to the classical psychological problem of how simultaneity judgments are made (Boring, 1950). We propose that simultaneity judgments (e.g., of a light and a click) are based on attention shifts from one modality or stimulus channel to another[2] and, in the

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[2] For a model that proposes attention shifts without memory from one modality to another, see Kristofferson (1967).

case of sophisticated subjects, also on reconstructive memory. The lability of simultaneity judgments is explained as being a property of the memory-reconstruction algorithms that are available to subjects in typical test situations. The extraordinary dependence of simultaneity judgments on mental "set" is due to the choice of which channel is the trigger for the attention shift.

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