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# DURATION ESTIMATES OF TWO INFORMATION PROCESSING COMPONENTS *

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Adult humans attempted to make quick responses to the first of two sequentially presented visual stimuli. At short interstimulus intervals (less than about 100 msec) accuracy was impaired by a different second stimulus and this was hypothesized to reflect the activity of an information processing component concerned with stimulus registration. At longer interstimulus intervals (up to approximately 350 msec) reaction time was inhibited by a different second stimulus and this was assumed to reflect the activity of a second component concerned with decision. The stimulus registration component was insensitive to variations in the complexity of the task, while the decision component was found to be greater for a task requiring recognition (is the current stimulus the same as an earlier one?) than for one merely requiring choice (what is the current stimulus?). This functional independence and the sizeable difference in the temporal range of susceptibility led to the conclusion that two distinct information processing components were involved.

Much of contemporary cognitive psychology has been devoted to theorizing about the nature of unobservable mental processes, and many theorists have postulated the existence of elaborate sequences of information processing stages intervening between overt stimuli and responses (e.g., Posner 1978; Salthouse 1981; Sanders 1980; Sternberg 1969, 1975). Because the internal processing components are not themselves directly observable, researchers must rely on a variety of converging procedures (e.g., subtractive method, additive-factors method) to infer the existence, and the properties, of these components. Although the information processing methods have been quite useful

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for determining the characteristics or efficiency of particular mental components, there has been much less progress in identifying the durations of specific components or the temporal relationship among different components. A valuable addition to the methodological repertoire of information processing researchers would be a technique that allows the simultaneous measurement of the time course of at least two different components.

The present research focuses on this goal by utilizing a technique introduced by Salthouse et al. (1981) to determine the duration of, and temporal relationship between, two processing operations. Salthouse et al. used the technique to explore determinants of eye fixation duration, but it seems readily adaptable to reaction time situations. The procedure is based on the successive presentation of two visual stimuli in the same spatial location. On one-half of the trials (SAME trials) the first and second stimuli are identical, and since the rate of stimulus replacement was very rapid, there is no noticeable change in the display. On the other half of the trials (DIFFERENT trials), the first and second stimuli are different. In all trials the subject is instructed to respond as rapidly as possible to the first stimulus perceived and ignore any later stimuli.

By varying the interstimulus interval between the first and second stimuli the temporal relationships of two different information processing components can be determined. The time course of one component is derived from an examination of the percentage of responses to the first stimulus when the first and second stimuli are the SAME compared to when they are DIFFERENT. The interstimulus interval at which response accuracy becomes equivalent for DIFFERENT stimulus and SAME stimulus trials can be interpreted as the completion time of an initial processing component concerned with stimulus registration. As noted in Salthouse et al. (1981), this comparison is very similar to that obtained in visual backward masking experiments as the interval at which DIFFERENT (masked) and SAME (unmasked) trials yield comparable accuracy is analogous to the time to escape backward masking.

The time course of a second component can be inferred from an examination of the reaction times in trials where the two stimuli were DIFFERENT compared to where they were SAME. If a new stimulus arrives while an earlier one is still being processed the reaction time may be delayed because of a disruption in an important processing component. The mechanism responsible for the disruption cannot yet be identified, but if the increased reaction time is interpreted as reflecting the susceptibility period of the component its duration can be estimated by determining the interstimulus interval at which reaction time becomes equivalent for DIFFERENT stimulus and SAME stimulus trials. Salthouse et al. (1981) found that an increase in the number of stimuli associated with each response increased the duration of this component but not the registration component, and thus the second component can be postulated to be concerned with higher-level, decision processes.

In the present study two tasks of differing cognitive complexity were employed to verify the distinction between the two processing components in a reaction time context. The Choice task simply involved the subject responding as rapidly as possible by pressing the left response key when the imperative stimulus was an 'X', and pressing the right response key when the imperative stimulus was an 'O'. The Recognition task began with the presentation of an initial 'X' or 'O' followed shortly later by another 'X' or 'O'. The subject was instructed to respond as rapidly as possible by pressing the left response key if the initial and imperative stimuli were the 'same', and by pressing the right response key if the initial and imperative stimuli were 'different'. Note that despite the differences between the Choice and Recognition tasks, the same type of responses (left or right key press) were required to exactly the same type of stimuli (a single 'X' or 'O') in both situations.

Two experiments were conducted. In experiment 1 the interval between the onset of the first and second imperative stimuli ranged from 20 to 200 msec, and in experiment 2, which was otherwise identical, the intervals ranged from 40 to 400 msec.

It was predicted that the time course of the function relating interstimulus interval to accuracy (the index of the first component) would be constant across the Choice and Recognition tasks. However, the function relating interstimulus interval to the increase in reaction time for DIFFERENT compared to SAME trials (the index of the second processing component) was expected to be much greater in the more demanding Recognition task.

Because the two components are inferred from the same tasks and are measured along the same time scale, it should also be possible to draw conclusions about the temporal relationships between the two components. Among the possibilities that can be explored are: (a) that the two components both begin at stimulus onset and terminate at approximately the same time, i.e., concurrent or parallel operation; (b) that one component begins at about the time the other component ends, i.e., discrete serial operation; (c) that the two components are partially concurrent but one extends over a longer duration than the other, i.e., overlapping serial operation; and (d) that there is a temporal gap between the termination of one component and the initiation of the other component, possibly due to the presence of an additional component intervening between the measured components.

## The experiments

### *Method*

#### *Subjects*

The *S*s were 32 college students, 16 in each experiment, each participating in two 1-hour sessions.

#### *Apparatus*

A PDP-11/03 laboratory computer was used to present stimuli on a Hewlett-Packard Model 1311A Display Monitor and record responses from a response panel containing microswitch response keys. The stimuli (X and O) were constructed by patterns of dots within a 16 by 24 (1.2 by 1.8 degree) matrix. A fixation stimulus consisted of four dots at the corners of the matrix. Reaction time in msec was recorded from the onset of the first imperative stimulus.

#### *Procedure*

One-half of the *S*s received the Choice task on the first session and the Recognition task on the second session, while the other half of the *S*s received the tasks in the opposite order. Each session consisted of six trial blocks of 200 trials each, but the first block was considered practice and the data were not analyzed. Within a trial block, the two trial types (SAME and DIFFERENT) and the ten interstimulus intervals (20 to 200 msec in experiment 1, and 40 to 400 msec in experiment 2) were randomly varied. Each *S* therefore received approximately 50 trials at each combination of interstimulus interval and trial type for both the Choice and Recognition tasks.

A trial in the Choice task involved the following sequence of events. First, a fixation stimulus (four dots) appeared for either 500, 1000, or 1500 msec (to minimize temporal anticipations). Immediately following was the first imperative stimulus (S1), either an 'X' or an 'O', which remained on for from 20 to 200 msec (for experiment 1) or from 40 to 400 msec (for experiment 2). Immediately after the offset of the first imperative stimulus the second imperative stimulus (S2) was presented in the same spatial location as the first. This second imperative stimulus remained on until the *S* pressed either the right or left key on the keyboard. SAME trials were those in which the first and second imperative stimuli were identical (i.e., 'X' followed by 'X', or 'O' followed by 'O'), while DIFFERENT trials were those in which the second imperative stimulus was different from the first imperative stimulus (i.e., 'X' followed by 'O', or 'O' followed by 'X').

A trial in the Recognition task was identical to that in the Choice task except that the fixation stimulus was preceded by a 500 msec presentation of an 'X' or an 'O' and a 300 msec blank interval. This initial stimulus served as the comparison against which the imperative stimulus was to be evaluated. If the comparison and the imperative were the same, the *S* was to press the left key as quickly as possible. On the other hand, if the comparison and imperative stimuli were different, the *S* was to press the right key as quickly as possible. As in the Choice task, the first (S1) and second (S2) imperative stimuli could be the same (SAME trials), or they could be different (DIFFERENT trials).

It is important to note that in both tasks there was a fixed assignment of stimuli to responses, but SAME trials occurred as frequently as DIFFERENT trials with each response. Since the comparisons of interest are between SAME and DIFFERENT trials rather than between X/O or match/no-match trials, the fixed response assignment does not involve a confounding with the primary manipulation.

*Results*

The percentages of responses to the first imperative stimulus (S1) for SAME and DIFFERENT trials in experiment 1 are illustrated in fig. 1. An analysis of variance on the DIFFERENT trial + SAME trial difference scores revealed a significant interstimulus interval effect ($F(9, 135) = 86.81$, $MSe = 94.44$, $p < 0.0001$), but no task effect nor task × interstimulus interval interaction (both $F$'s $< 1.03$). As can be inferred from fig. 1, the difference scores for both tasks were significant ($t(15) > 2.67$, $p < 0.05$) at intervals from 20 to 80 msec, and were also significant at 100 msec for the Choice task, but were not significant beyond that point.

Fig. 2 illustrates the reaction time data for all trials, correct and incorrect, from experiment 1. A DIFFERENT–SAME difference score analysis of variance indicated that the interstimulus interval $F(9, 135) = 8.82$, $MSe = 1952.80$, $p < 0.0001$) and task ($F(1, 15) = 8.12$, $MSe = 11070.48$, $p < 0.05$) main effects were significant, but not their interaction ($F < 1.40$). The DIFFERENT–SAME difference was significant ($t(15) > 2.70$, $p < 0.05$) at all interstimulus intervals for both tasks, and thus the time course of the second component could not be determined from the data of experiment 1. Experiment 2 was therefore designed with a greater range of interstimulus intervals to allow measurement of the temporal range of this second processing component.

Fig. 3 illustrates the accuracy data from experiment 2. Once again the analysis of variance revealed a significant effect of interstimulus interval ($F(9, 135) = 54.09$, $MSe = 59.14$, $p < 0.0001$), but not task nor the interaction of interstimulus interval × task (both $F$'s $< 1.0$). As in experiment 1, the Choice and Recognition tasks exhibited the same trends of significant ($t(15) > 3.12$, $p < 0.05$) DIFFERENT–SAME differences for short intervals (40 to 80 msec for Choice, 40 to 120 msec for Recognition), but not for long intervals.

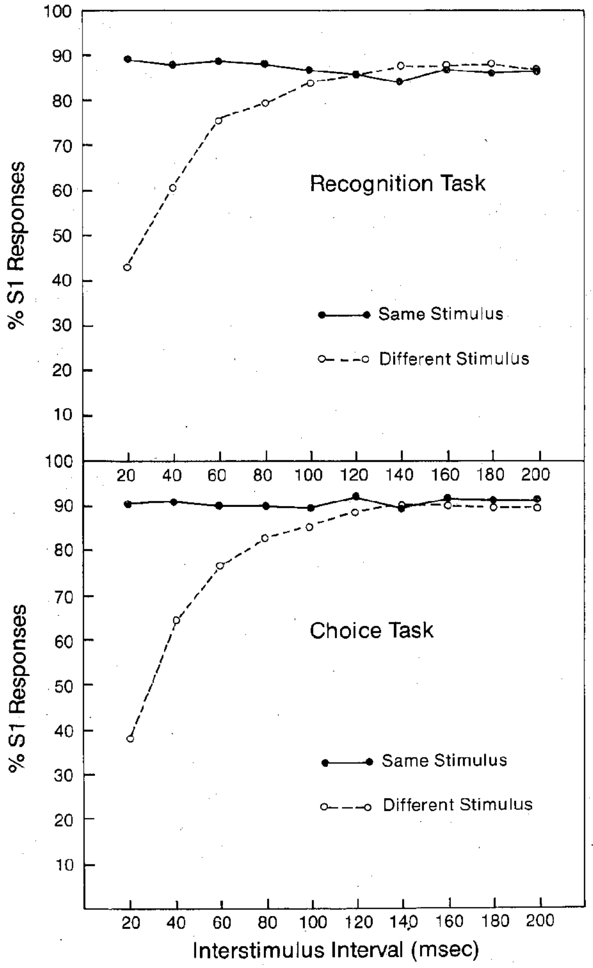


Fig. 1. Percentage of responses to the first imperative stimulus (S1) as a function of interstimulus interval between first (S1) and second (S2) imperative stimuli, Experiment 1.

The reaction time data of experiment 2, based on both correct and incorrect trials, are illustrated in fig. 4. The difference score analysis of variance indicated that all effects were significant: interstimulus interval ($F(9.\ 135) = 36.19$, $MSe = 2159.67$, $p < 0.0001$), task ($F(1,\ 15) = 20.39$. $MSe = 5347.41$, $p < 0.0005$), and interstimulus interval $\times$ task ($F(9,\ 135) = 6.19$, $MSe = 1567.86$, $p < 0.0001$). The difference scores were significant ($t(15) > 2.28$, $p < 0.05$) in the Choice task from 40 to 160 msec, and in the Recognition task from 40 to 320 msec.

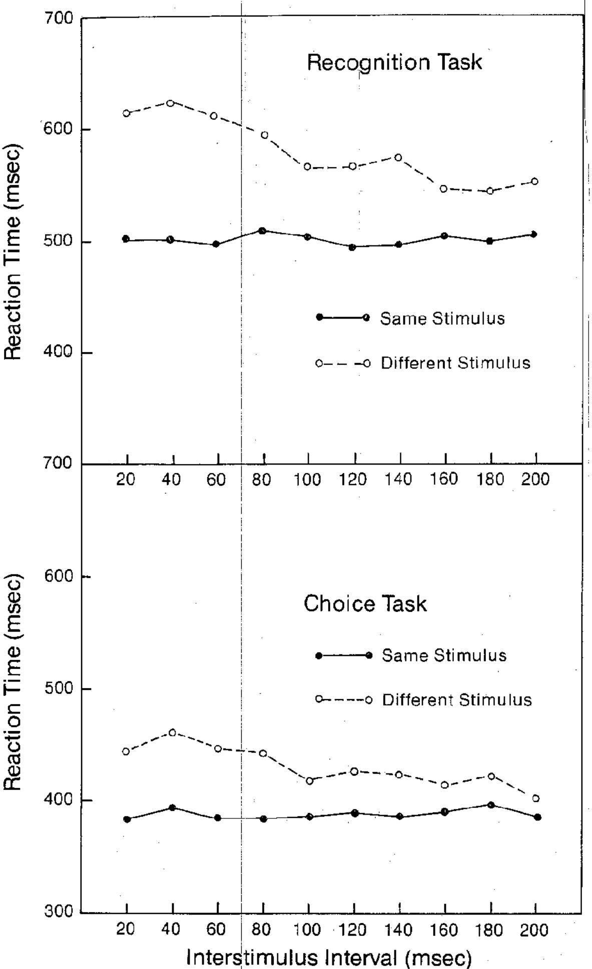


Fig. 2. Reaction time to the first imperative stimulus (S1) as a function of interstimulus interval between first and second imperative stimuli, Experiment 1.

Estimates were also obtained from the data of each individual subject of the durations of the two inferred processing components, and the peak magnitude of the reaction time delay effects. The duration of the first processing component was determined by identifying the interstimulus interval at which the accuracy of DIFFERENT stimulus trials first equalled or exceeded the mean accuracy, across all intervals, of SAME stimulus trials. The mean durations for experiment 1 were 128 msec for the

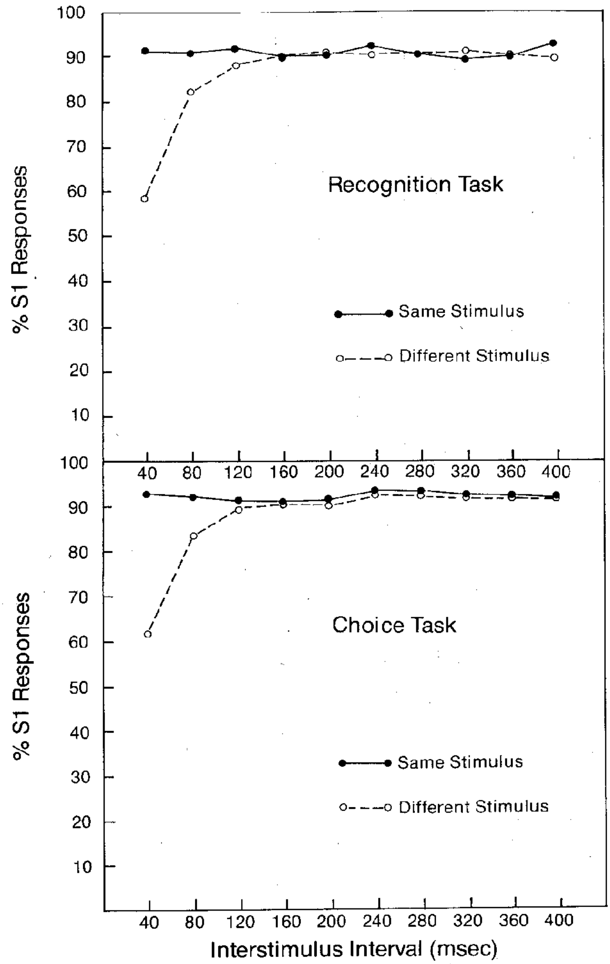


Fig. 3. Percentage of responses to the first imperative stimulus (S1) as a function of interstimulus interval between first (S1) and second (S2) imperative stimuli, Experiment 2.

Choice task, and 113 msec for the Recognition task ($t(15) < 1.3$, $p > 0.20$). Mean durations for experiment 2 were 193 msec for the Choice task and 158 msec for the Recognition task ($t(15) < 1.3$, $p > 0.20$). The larger estimates in experiment 2 are probably attributable to the bigger increment sizes and greater range of interstimulus intervals. The estimation procedure will tend to assign a duration at the interval just above the true value, and if the intervals are separated by 40 msec rather than 20 msec

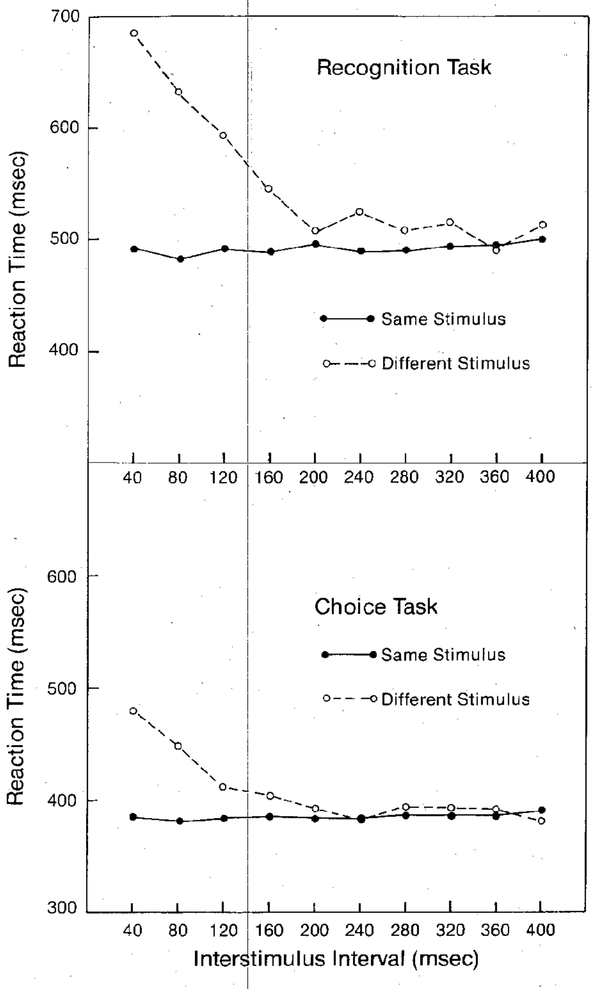


Fig. 4. Reaction time to the first imperative stimulus (S1) as a function of interstimulus interval between first and second imperative stimuli, Experiment 2.

the estimates will be systematically greater with the larger increment size. It is also true that the average value will tend to increase as the range of interstimulus intervals increase simply because of the higher maximum value that can be reached when estimation errors occur.

The duration of the second processing component was determined for each *S* by identifying the interstimulus interval at which the reaction time for DIFFERENT stimulus trials first equalled, or fell below, the mean reaction time across all intervals for SAME stimulus trials. Because DIFFERENT reaction times were significantly greater than SAME reaction times for all intervals in experiment 1, no estimates could be obtained from that experiment. The means for experiment 2 were 173 msec for the Choice task and 285 msec for the Recognition task ($t(15) = 4.15$, $p < 0.01$).

An estimate of the duration of residual processing components was obtained in experiment 2 by subtracting the duration of the second processing component from the mean reaction time for SAME stimulus trials. These values averaged 213 msec for the Choice task, and 207 msec for the Recogniton task ($t(15) < 1.00$).

The peak magnitude of the reaction time delay effect was computed for each individual $S$ by subtracting the mean reaction time for SAME stimulus trials from the maximum reaction time, across all intervals, for DIFFERENT stimulus trials. The means for experiment 1 were 94 msec for the Choice task and 170 msec for the Recognition task ($t(15) = 4.22$, $p < 0.01$). The means for experiment 2 were 104 msec for the Choice task and 197 msec for the Recognition task ($t(15) = 4.03$, $p < 0.01$).

## Discussion

A major finding of the present experiments is that a manipulation, i.e., Choice or Recognition, that has substantial effects on reaction time has virtually no effect on a dependent measure (accuracy) assumed to reflect the operation of one processing component, but large effects on a dependent measure (reaction time delay) assumed to reflect the operation of a second processing component. In both respects these results replicate those reported earlier in an eye movement context (Salthouse et al. 1981), and extend them to a new manipulation of decisional complexity.

While the differential susceptibility to task complexity suggests that the two components are functionally distinct, the nature of the processing involved in each component is not immediately obvious. In view of the similarity of the functions in figs. 1 and 3 to visual backward masking functions, it seems reasonable to argue that the component represented by the accuracy measures is the same as that investigated in backward masking experiments. Indeed, a recent experiment (Salthouse 1982) utilizing backward masking procedures with the same tasks and apparatus as in the current study reported 75% duration thresholds of 59.7 and 58.1 msec, respectively, for the Choice and Recognition tasks. Inspection of figs. 1 and 3 reveals that nearly identical values would be obtained at accuracy levels of 75% in the present experiments.

In addition to the present study, the absence of an effect of task complexity on a measure of visual backward masking has been demonstrated in two other studies each involving two relevant experiments (Salthouse 1982; Salthouse et al. 1981). It must be concluded, therefore, that the processing component reflected in visual backward masking measures is primarily responsible for establishing a stimulus representation, but not for performing important cognitive operations on that representation.

The existence of the second processing component is inferred from the delayed reaction times for DIFFERENT trials relative to SAME trials. It is assumed that the delay is produced by a disruption in the processing of the first stimulus caused by the occurrence of a different second stimulus.

A similar reaction time delay phenomenon with spatially separated stimuli was reported by Helson and Steger (1962), although there has been some difficulty in replicating the initial phenomenon (e.g., Kitterle and Helson 1972; Koplin et al. 1966; Lappin and Eriksen 1964). The imposition of a 400 msec ceiling on the maximum reaction time in the unsuccessful attempts at replication, but not in the successful ones, may have been a major factor responsible for the discrepant results. One must expect a greater proportion of long reaction times if a delay effect is to be produced, and disallowing such reaction times may completely eliminate the effect.

Herman and Kantowitz (1970) have also reviewed a number of studies employing a double-stimulation procedure in which longer reaction times to the first stimulus have been reported when a second stimulus followed at relatively short interstimulus intervals. Despite the finding that greater delay effects are found when the second stimulus does not require a response (e.g., Herman and McCauley 1969; Knight and Kantowitz 1974), these authors favored an interpretation which localized the delay phenomenon in response processes (e.g., selection, preparation or execution).

In contrast, the current interpretation of the reaction time delay phenomenon is that the increased time is produced by a disruption of a cognitive component concerned with decision rather than response. One result supporting this interpretation is the finding by Salthouse et al. (1981) that with a 5-to-1 mapping of stimuli to responses, a change in the stimulus that did not require a different response produced comparable delays to a change in the stimulus that did require a different response. In other words, it was the change in the stimulus that was critical, and not the fact that a competing response was involved.

The second result arguing for a decisional involvement is the finding that the duration and the peak magnitude of the delay is greater with tasks having more demanding memory and/or decision requirements. In the Salthouse et al. (1981) study an odd/even digit classification produced greater delays than a left/right arrow classification. In the present experiments the Recognition task produced greater delays than the Choice task. The critical distinction between these tasks seems to be the degree of decision and not any response factor since in all cases the same two (left or right) responses were involved.

It is useful to try to place the current processing components into the taxonomic schemes proposed by earlier investigators. In Welford's (1960) three-component model of perceptual, translation, and central effector mechanisms, the present registration component would probably fall within the perceptual mechanism while the decision component would be roughly analogous to Welford's translation mechanism. Smith (1968) proposed four components – stimulus processing, stimulus categorization, response selection, and response execution, and the current registration component might be assigned to Smith's stimulus processing stage while the decision component might be considered comparable to Smith's stimulus categorization process. In terms of Sternberg's (1969) very influential four-component model – stimulus encoding, stimulus comparison, decision, and translation and response organization – registration is probably most like stimulus encoding while the two decision components are probably equivalent. The similarity in the structural inferences that have been drawn from a variety of different analyses of reaction time components suggests that several different processing components are indeed involved in the reaction time task.

In addition to extending the evidence for functionally distinct components in information processing, the present data can also be used to make inferences about the approximate durations and temporal sequence of the processing components. For example, one conclusion is that the components were not completely concurrent because DIFFERENT trials had lower accuracy (reflecting the first component) only up to time intervals of about 100 to 160 msec, while the longer reaction times (indexing the operation of the second component) were evident up to 320 msec. If the components had been exactly simultaneous one might have expected the measures reflecting their activities to exhibit the same initiation and termination points, but it is clear that the termination points differ substantially.

It can also be inferred that the components were temporally contiguous since the reaction time delay was evident at temporal intervals at or before the time that DIFFERENT accuracy asymptoted. Only if there were a temporal gap between the completion of one component and the initiation of the second component would it be likely that another component intervened between the two components investigated here.

The fact that the reaction time delay indicated activity of the decision component throughout the duration of the first component can also be interpreted as evidence for temporally overlapping processing (e.g., Eriksen and Schultz 1979; McClelland 1979). Both processing components seem to be active at the shortest intervals examined and thus it appears unlikely that the decision component begins only after the registration component is completed.

To summarize, the current data suggest that there are at least two distinct processing components involved in reaction time tasks, and that these components: (a) require approximately 100 to 160 msec and up to 320 msec, respectively; (b) are temporally contiguous with no other intervening components; and (c) are temporally overlapping with both components simultaneously active. The existence of specialized processing components is now quite convincing in light of the large body of previous research. Further evidence for the remaining three conclusions of the present study is now needed from a variety of procedures in order for these inferences to achieve the same status as the first conclusion.

A final intriguing aspect of these data is the relatively large (210 msec) difference between the total reaction time and the duration of the second component. Since the second processing component is sensitive to the cognitive demands of the task, it is not clear why such a long period would be needed to translate a decision into a response. Additional techniques capable of exploring the nature of the information processing activity occupying the last 50% to 70% of the total reaction time would be highly desirable.

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