JOURNAL OF THE EXPERIMENTAL ANALYSIS OF BEHAVIOR 1985, 44, 1-14 NUMBER 1 (JULY)

REACTION TIMES OF YOUNGER AND OLDER MEN: EFFECTS OF COMPOUND SAMPLES AND A PRECHOICE SIGNAL ON DELAYED MATCHING-TO-SAMPLE PERFORMANCES

ALAN BARON AND STEPHEN R. MENICH

UNIVERSITY OF WISCONSIN-MILWAUKEE

Five younger (18 to 23 yrs) and five older (65 to 73 yrs) men were exposed to a series of immediate and delayed (0 to 15 seconds) matching-to-sample problems. Presentation of the pairs of delayed comparison stimuli was either signaled or unsignaled, and the sample contained either 1, 2, or 3 elements, one of which appeared as the positive stimulus. During initial sessions, unlimited time was available to respond. Subsequently, correct responses were reinforced only if they occurred within a specified time limit. A general finding was slower responding with increased delay and with increased number of sample elements. These effects were reduced when the comparison stimuli were signaled and when time limits were in effect. Errors increased as a function of the manipulations of sample complexity and time limits, but did not change systematically when the delay between sample and comparison stimuli was varied. Although the younger men generally responded more quickly than the older ones, men of both ages showed increased speeds when limits were placed on response time, and these changes were maintained when the temporal contingencies were removed.

Key words: reaction time, temporal contingencies, stimulus complexity, signaled discrimination, delayed matching to sample, practice effects, young and old adult humans

---

Reaction time frequently is interpreted as an indicator of the speed of unobserved inner events such as the time required for cognitive processing or the rate at which information is transmitted within the nervous system (Welford, 1980). But reaction time also is a property of behavior in its own right, and the speed of an operant response should be sensitive to environmental events contingent on the response. Support for this view comes mainly from experiments that found that response speeds of animal subjects (rats, monkeys) were influenced by the magnitude of the reinforcer and by contingencies based on fast versus slow responding (e.g., Moody, 1970; Saslow, 1968, 1972; Stebbins, 1962, 1966). But a few experiments with humans suggest similar conclusions (e.g., Baron, Menich, & Perone, 1983; Church & Camp, 1965; Johanson, 1922).

Research on human reaction time usually has not followed behavior-analytic procedures in that observations have been brief (for some exceptions, see review by Salthouse & Somberg, 1982) and in that experimental designs have involved group comparisons. Another set of differences pertains to the variables controlling rapid responding. In animal experiments on reaction time, subjects are studied under specified motivational conditions and rapid responding is explicitly reinforced. In contrast, experiments with human subjects rely on instructions to induce rapid responding. The subject is told to "respond as rapidly as you can," and there are no rewards or penalties for rapid or slow responding.

In a previous experiment (Baron et al., 1983), we studied human reaction time using steady-state procedures and reinforcement variables as alternatives to the usual brief observations and verbal interventions, and

This research was supported by Grant AG02513 from the National Institute on Aging and by the Graduate School and College of Letters and Science of the University of Wisconsin-Milwaukee. The assistance of Tom Doolittle and Jeanne Dawson in collecting the data is gratefully acknowledged. Reprints may be obtained from Alan Baron, Department of Psychology, University of Wisconsin-Milwaukee, P.O. Box 413, Milwaukee, Wisconsin 53201.

found that early performances were not indicative of ultimate capabilities. The subjects, older and younger men, were exposed to an extended series of matching-to-sample and oddity-matching problems with monetary reinforcement contingent on correct responses. Response speeds increased substantially when reinforcers were produced only by responses that occurred within a specified time limit; these increased speeds were maintained when the temporal contingency was removed. The experiment reported below extended the investigation to delayed discriminations. Although delayed matching-to-sample discriminations have been a powerful tool for the study of short-term memory in animals (Roberts & Grant, 1976), the procedure has rarely been used with human subjects (but see Sidman, 1969). We wondered whether response speeds would vary as a function of the sample-choice interval and whether responding would be influenced by imposition of temporal contingencies.

A special feature of this and our previous research (Baron & Menich, 1985; Baron et al., 1983; Perone & Baron, 1983) is that the subjects included both younger and older adults (c. 20 years vs. c. 70 years). A well known finding in the psychology of aging is that response speed is negatively correlated with age (Birren, Woods, & Williams, 1980). Comparisons of individuals who respond with characteristically different speeds (e.g., young and old subjects) provide a more comprehensive picture of the experimental variables under study as well as a link with traditional studies of human individual differences (Baron & Perone, 1982). Behavioral differences correlated with age commonly are viewed as reflecting irreversible deficits, perhaps due to central nervous system changes. But slow responding also may be a consequence of environmental influences such as lack of practice, unfamiliarity with the testing procedures, or insufficient reinforcement of rapid responding, in which case age differences may be modifiable by altering contingencies.

A related finding is that age differences in response speed become progressively greater as the complexity of the task is increased (Cerella, Poon, & Williams, 1980). The present procedures examined the role of complexity by varying the number of elements contained within the sample stimulus. Other findings suggest that age-correlated deficits may reflect impaired ability to prepare for critical stimuli (Kausler, 1982). This second consideration led us to investigate the effects of signaling the choice phase of the delayed discriminations.

METHOD

Subjects

Five younger men (18 to 23 years) and five older men (65 to 73 years) volunteered to serve in a laboratory experiment in which payment depended on performance. All were living independently in the Milwaukee community and were taking courses at the university (the younger as undergraduate students and the older in a course-audit program for older adults). According to a medical questionnaire, all were in good health and none had been hospitalized during the previous year. Performances on the Wechsler Adult Intelligence Scale placed the men at or above average levels for the general population.

After a preliminary session, the men gave their informed consent to participate in the research by signing a contract to serve for at least 40 hrs scheduled over 3 to 5 weeks. Payment included $2.00 per hour plus additional money that could be earned during the sessions (about $2.00 per session). Compensation also was provided for travel expenses based on the prevailing round-trip bus fare. To ensure completion of the project, the hourly payments were contingent on completion of all scheduled sessions. At the end of each session, the amount earned was displayed on the video monitor in the experimental room, and a written receipt also was provided. Actual payment was postponed until completion of each man's participation.

Apparatus

Experimental sessions were conducted in a sound-attenuating room, 1.8-m square. The man sat facing a console that included a 12-in. (31 cm) video monitor for presenting visual stimuli, two telegraph keys for measuring reaction time, and a pushbutton. The monitor was mounted on a base so that the center of the screen was 45 cm above the table top. The knobs of the telegraph keys, which moved 1 cm when pressed or released, protruded 2 cm from the left and right sides of the base. When the man was seated at the table, the screen was at eye level approximately 50 cm away, and the two keys were at arm's length.

Mounted under the table directly to the right was a spring-loaded plunger (Gerbrands) that operated if pulled a distance of 2.5 cm with a force of at least 2 lbs (about 9 N). A speaker on the right wall delivered auditory stimuli. Control and recording equipment in a nearby room included a microcomputer and accessory electromechanical components.

General Procedure

Details of the procedure have been described previously (Baron & Menich, 1985; Baron et al., 1983). Each session lasted approximately 50 min, and two sessions, separated by a 10-min rest period, were conducted on a given day. Choice reaction times were measured using a matching-to-sample procedure in which presses and releases of the telegraph keys were the responses and displays on the screen were the stimuli. The schedule contained two links. Pulling the plunger and then holding down both keys (with the two forefingers) produced the second link, a discrimination trial. The sample stimulus then appeared in the center of the screen for 2 s (the foreperiod) followed by the two comparison stimuli on the left and right sides (the choice period). One comparison stimulus matched the sample and the other was different, and release of the key corresponding to the matching stimulus was counted as a correct response.

Release of the keys produced different messages on the screen depending on whether the match was correct or incorrect. After release of the correct key, the message, "Correct," appeared and operation of the pushbutton produced the further message, "You have earned 1 credit." The schedule then returned to the initial link in which a plunger pull was required to start the next trial. The sequence of events after release of the incorrect key was similar except that the messages were "Wrong," and "You have lost 0 credits" (the latter message allowed the possibility of reinforcement loss following errors; however, this option was not used in the present experiment). Lifting of both keys during the choice period also was treated as an error, except that the message following the responses was, "Wrong—you released both keys." Finally, key releases before display of the comparison stimuli (foreperiod responses) produced the message, "You released the key too soon," and the schedule then reverted to the initial link for the start of a new trial. Session earnings, based on the number of credits that were accumulated, were reported on the screen at the end of the session (as well as on a receipt given to the subject).

The stimuli displayed on the screen were either nonalphanumeric typewriter keyboard symbols (e.g., "#", "?", "$") or graphic patterns consisting of 2 to 12 small rectangular cells within a 4 by 3 matrix (10 by 13 mm). At least 1 and as many as all 6 of the cells in each half of the matrix could be illuminated (when all 12 cells were lit the stimulus appeared as a continuous rectangle, 10 by 13 mm). Close to 4000 unique stimuli could be produced this way. The first two pairs of young and old men were exposed to exploratory manipulations involving the stimuli. For the men of Pair 1, the keyboard symbols served exclusively as the sample and comparison stimuli, and sessions with all eight stimuli (drawn randomly from the pool) alternated with sessions in which only two stimuli were used. The men of Pair 2 were used to determine whether the unfamiliar graphic characters would induce more errors (errors were infrequent with keyboard symbols), and sessions with two symbols alternated with sessions in which the stimuli were randomly drawn from the pool of graphic patterns. For the remaining men (Pairs 3 to 5), the procedure with the graphic patterns was followed exclusively.

Experimental Variables

All of the men were exposed to variations in the sample-comparison delay intervals and to the presence or absence of a signal preceding the choice period. These two variables were manipulated within each session. Only Pairs 3 to 5 were exposed to procedures that varied the number of elements contained within the sample stimulus. Finally, all of the men were exposed to time limits; the exact values, however, were different for Pairs 1 and 2 and Pairs 3 to 5.

Delay intervals. The schedule was arranged so that the pair of comparison stimuli appeared immediately following the sample (0-s delay) or after delays of 5, 10, or 15 s. The session was divided into four components, each containing a block of 50 discriminations with the same delay (half were signaled and half were unsignaled; see below). The components were presented in the order, 0 s, 5 s, 10 s, 15 s and were separated by 40-s "intermissions."

Warning signal. The choice period of the delayed trials could be signaled or unsignaled. On signaled trials, a 500-Hz tone (approximately 70 dB intensity, measured where the man sat) was presented for 2 s immediately prior to the appearance of the comparison stimuli (the tone terminated with the appearance of the stimuli). This signal occurred on half of the delayed trials (i.e., 5, 10, and 15 s) according to a random sequence with the restriction that it was present on no more than three consecutive trials.

Simple versus compound samples. For Pairs 3 to 5, trained exclusively with the graphic patterns, the sample stimulus was either a single pattern (simple sample) or was composed of two or three patterns (compound sample) arranged in a horizontal row. In all cases, each of the comparison stimuli was a single pattern. When the sample stimulus was a compound, the correct response was to the comparison stimulus that was an element of the compound. Sessions with one, two, or three sample elements occurred in sequential order.

Time limits. During an initial baseline series, unlimited time was available in which to respond. Time limits then were placed on responding, followed by additional sessions when the limits were removed (the men were informed when limits were in effect but were not given information about the specific durations). Under time-limit conditions, the message, "You released the key too late," followed a response that did not occur within the limit, and the schedule reverted to the initial link without reinforcement being delivered.

Table 1

Sequence of time-limit conditions and number of sessions under each.

Time Limit (Speed)	*Pair 1 18-73*		*Pair 2 22-69*		*Pair 3 23-71*		*Pair 4 23-65*		*Pair 5 22-72*	
BL	16	12	12	12	12	12	12	12	12	12
0.50	–	–	–	–	6	6	6	6	6	6
0.75	–	4	–	–	–	–	–	–	–	–
1.00	4	4	4	4	6	6	6	6	6	6
1.50	8	6[a]	8	8	9	9	9	6[b]	9	9
2.00	8	8	8	8	–	–	–	–	–	–
BL	4	4	4	4	6	6	6	6	6	6

[a]Two sessions omitted because of a procedural error
[b]Third replication (three sessions) omitted because of time constraints

Table 1 summarizes the sequence and number of baseline and time-limit sessions to which each man was exposed (note that time limits were treated as speeds, i.e., 1000/ms). The initial baseline series included at least 12 sessions (16 for Subject Y1) and the initial and terminal baseline sessions were separated by a series of increasingly severe time limits (18 to 21 sessions).

The precise number of sessions devoted to each condition was dictated by practical considerations (the men contracted to serve for 40 sessions), as well as the combination of variables to which the men were exposed. During each session, data from approximately 25 responses could be collected for each unique combination of the delay and signal variables. Combination of two of these sets provided the total of 50 responses deemed necessary for the analysis. For Pairs 1 and 2, where the size of the stimulus pool alternated from session to session, this led to a plan in which six to eight data sets were collected during the initial baseline series, two sets during the first time-limit condition, four sets at each of the more severe limits, and two sets during the final baseline series (for Subject O1, the last four sessions of the initial baseline were replaced by a lax time limit to ease the transition to time-limit conditions). For Pairs 3 to 5, who were exposed to sample stimuli containing one, two, or three elements during consecutive sessions, the plan called for collection of four sets of data during the initial baseline series, two sets for each of the first two limits, three sets for the most severe limit, and two sets during the final baseline. Also to be noted is that the time limits to which Pairs 3 to 5 were exposed were less extreme than those for Pairs 1 and 2. This aspect of the procedure reflected the increased difficulty of the discriminations when the number of sample elements was increased from one to two or three.

Decisions to change conditions followed the above plan rather than consideration of data from individual subjects. The expectation that enough sessions were included to provide reliable information about individual performances generally was borne out. For each condition, the variation between data from the last set and the preceding one usually did not exceed 10% (82% of comparisons) and variation almost always was within 20% (97% of comparisons).

Instructions. Instructions included printed material as well as various messages presented on the screen. Essential features of material read prior to the first session were the following: (a) "To get a problem, you must operate the plunger." (b) "Your job is to indicate which of the two choice stimuli is correct by releasing the corresponding key." (c) Correct responses earn "credits" that are worth money. (d) "To operate the apparatus, you must release only one key per trial," and "if you release the key before the choice stimuli appear, the trial will end automatically." (e) "Our interest is in how rapidly you can release the correct key. To maximize your earnings you must be both correct and prompt." (f) "At first you will have unlimited time in which to choose. During subsequent sessions, you will be required to select the correct stimulus within a time limit." (g) "While you are in the room you can do whatever you like. But remember that your pay depends on what you do. If you should go to sleep, for example, your earnings for that session could amount to nothing."

RESULTS

Analyses are summarized below under two headings. First, the effects of the experimental variables on the performances of the individual subjects are described. This is followed by a consideration of age-related effects. Because age effects involved between-group comparisons, inferential statistical procedures were used to verify the reliability of age differences as well as interactions between age and the experimental variables.

The data were errors and response speeds. Response speeds were calculated by converting the time to respond to the comparison stimuli (recorded in milliseconds from onset) to its reciprocal (1000/ms). Depictions of performances as speeds—that is, as response rates (response/s) rather than as response latencies (s/response)—are customary in the study of instrumental conditioning (cf. Kimble, 1961) and have the statistical advantage of avoiding the positive skew that often accompanies latency distributions. The more important consideration is that treatment of data as response rates gives increasing weight (rather than equal weight) to decreased latencies, and for this reason provides a more sensitive description of behavioral changes as responding approaches its limit. (The individual performances depicted in the tables and figures below are the *medians* of distributions of response speeds, thus allowing conversion back to median latencies, e.g., 1.00 = 1000 ms; 1.50 = 667 ms; 2.00 = 500 ms, etc.)

Experimental Variables

Figure 1 presents a sequential picture of each man's response speeds at key points during the experiment: the start and end of the initial baseline phase, the phase when time limits were imposed, and the final baseline phase. The connected sets of points indicate the four delay conditions (0, 5, 10, and 15 s), with separate functions for the conditions with and without the signal. Each point in the figure is the median of approximately 50 responses collected over the two initial and two terminal sessions with one-element samples (and, for Pairs 1 and 2, the larger pool of stimuli), the

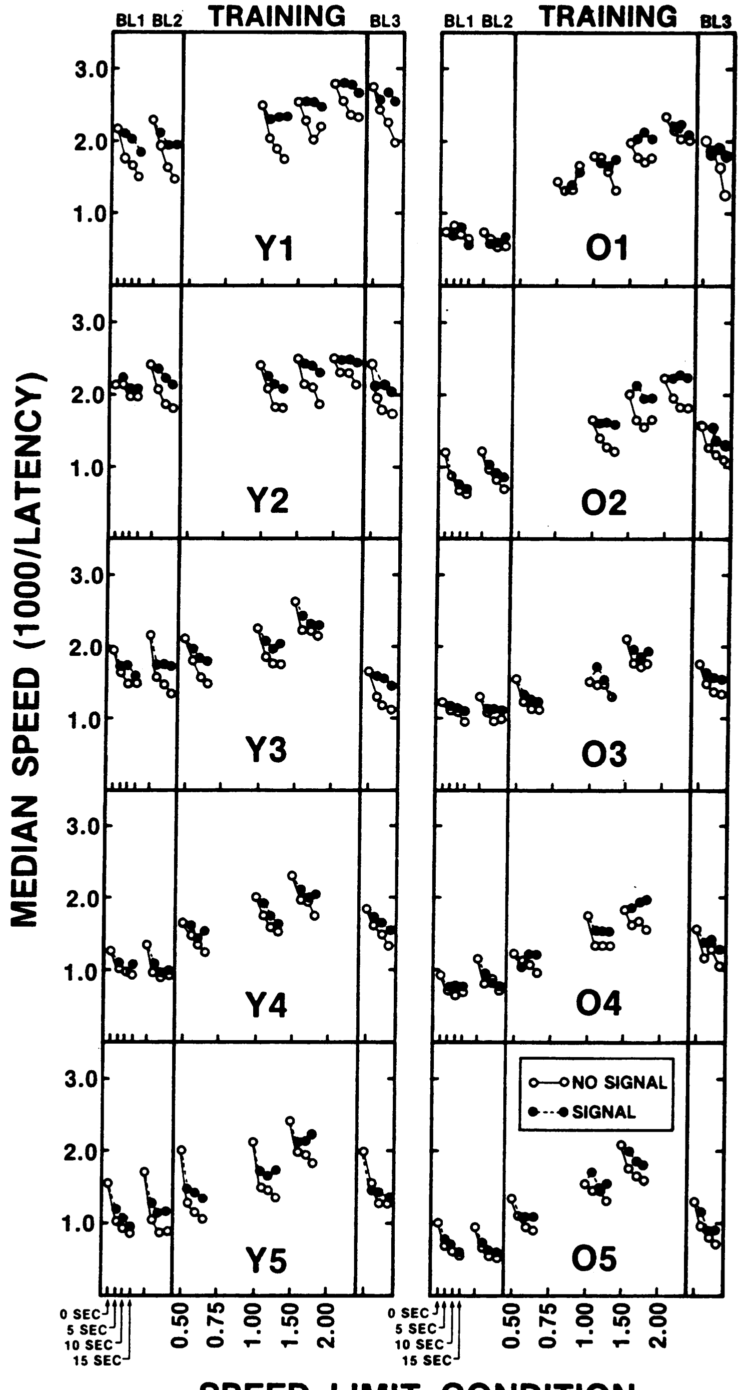

Fig. 1. Each set of connected points represents median response speeds (1000/latency) with the four delays (0, 5, 10, and 15 s) for each of the 5 younger men (left panels) and 5 older men (right panels). Data are from the beginning and end of the initial baseline series when there was unlimited time in which to respond (BL1 and BL2), from sessions when there were speed requirements (1000/ms), and from the second baseline series (BL3). Filled circles represent performances when a signal preceded presentation of the choice stimuli and unfilled circles indicate when the signal was absent.

common condition for all of the men.

Response speeds did not change much during the initial baseline series (compare BL1 and BL2). During this phase, as well as subsequent time-limit phases, responding was slower in the delayed discriminations than in the immediate ones, with the largest reductions tending to occur between the 0-s and 5-s delay conditions. The procedure of placing time limits on responding resulted in increased speeds for all of the men, most markedly for those with the lowest baseline levels. Generally, the time-limit manipulation had the effect of elevating the entire gradient, with speeds becoming progressively faster as the temporal contingency was made more stringent. The final procedure of removing the temporal contingency led to slower responding, although speeds did remain somewhat above pretraining levels (compare BL2 and BL3; an exception is Subject Y3). Another feature of the results pertains to the effects of signaling the delayed discriminations. Although there were some exceptions, under both baseline and time-limit conditions, responding tended to be faster under the signal condition relative to the unsignaled one, thus reducing the slope of the delay gradient. For most of the men, this effect became more pronounced as the time limits were made more stringent.

Figure 2 provides a parallel analysis of performance efficiency, expressed as the percentage of total responses that met the reinforcement criterion (i.e., responses that were both accurate and within the prevailing time limit). Outcomes under three conditions are compared: when the comparison stimuli immediately followed the sample (0-s delay), when the comparison stimuli were delayed for the longest interval (15-s delay), and when the delayed discrimination was signaled (for the time-limit conditions only).

The men acquired virtually all of the available reinforcers when they had unlimited time to respond (BL1, BL2, and BL3), but progressively fewer of their responses met the criterion as the various time limits were introduced. It is also apparent that performances under the time-limit conditions tended to be more efficient when the discriminations were

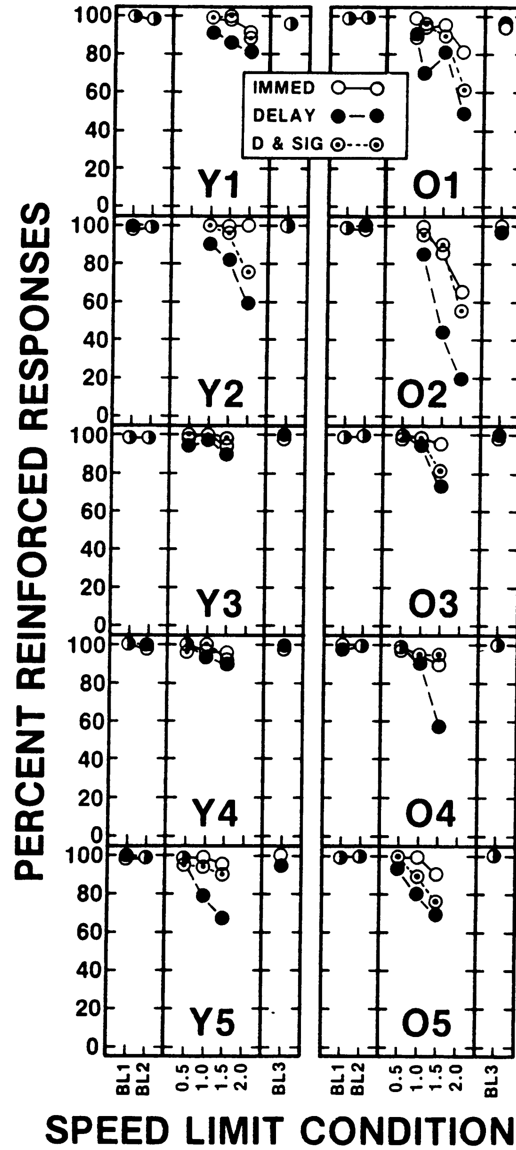

Fig. 2. Percentage of reinforced responses (correct and within the time limit) for each of the 5 younger men (left panels) and the 5 older men (right panels). Data are from baseline (BL) sessions when there was unlimited time in which to respond and sessions when there were speed requirements (1000/ms). Performances are shown when there was no delay between the sample and choice stimuli (immediate), when the choice stimuli were delayed for 15 s (delay), and when a 2-s warning signal preceded the delayed choice stimuli (delay & signal).

immediate than when they were delayed. With some exceptions, the effects of the delay became more marked with increases in the severity of the limits (exceptions were the three

Table 2

Percentage of errors: at the end of the initial baseline phase (BL2), averaged across the time-limit conditions (TL), and during the final baseline phase (BL3).

Subject Pairs		*Young*			*Old*		
		Imm	*Del*	*D+S*	*Imm*	*Del*	*D+S*
	BL2	1.0	2.0	0.0	0.0	0.0	0.0
Pair 1	TL	3.7	4.7	3.0	2.5	3.0	4.5
	BL3	4.0	4.0	7.0	0.0	3.0	0.0
	BL2	1.0	0.0	4.0	1.0	0.0	0.0
Pair 2	TL	1.0	4.0	2.7	6.7	25.0	12.0
	BL3	0.0	4.0	2.0	0.0	7.0	2.0
	BL2	2.0	2.0	2.0	0.0	0.0	0.0
Pair 3	TL	2.7	4.3	1.3	1.3	2.3	2.3
	BL3	2.0	0.0	0.0	1.0	0.0	0.0
	BL2	1.0	0.0	0.0	0.0	0.0	0.0
Pair 4	TL	1.7	0.7	2.0	1.7	4.0	2.0
	BL3	1.0	0.0	0.0	0.0	0.0	0.0
	BL2	1.0	2.0	0.0	0.0	0.0	0.0
Pair 5	TL	2.0	7.3	6.0	1.7	3.3	3.7
	BL3	0.0	4.0	0.0	0.0	0.0	0.0

Note: Imm = Immediate (0-s delay)
Del = Delay (15-s delay)
D+S = Signaled 15-s delay

men whose efficiency was least impaired: Y1, Y3, and Y4). Figure 2 also shows that performances were influenced by signaling the delayed discriminations. For most of the men, the signal reduced differences between the immediate and delayed discriminations (again, exceptions are Y1, Y3, and Y4).

Error rates for the five pairs of men may be seen in Table 2. The pattern of results shows that errors generally were infrequent across the various conditions of the experiment. (Note that data are from conditions with one-element samples; results with two and three elements are considered below.) Errors did increase somewhat when time-limit conditions were introduced (compare BL2 and TL; data are averaged across the various limits), but error rates remained low for most of the men and in only one case exceeded 10% (the exception is Subject O2). Table 2 also shows that more errors occurred when the discriminations were delayed than when they were immediate (see especially Y5 and O2 under time-limit conditions). But for most of the men, the procedure of delaying the discrimination did not appreciably elevate the otherwise low error rates.

Results from the three pairs of men exposed to variations in the number of sample elements (1, 2, or 3 elements) are summarized in Figure 3 (speed) and Figure 4 (errors). The different panels indicate response speeds under three delay conditions (0-s delay, 15-s delay, and 15-s delay plus signal), and the separate functions within each panel show speeds at the end of the initial baseline series and the following time-limit conditions: 0.5 and 1.0 for the speed analysis; 0.5, 1.0, and 1.5 for the error analysis. (The most extreme condition, 1.5, was excluded from the speed analysis because of high error rates; see below.)

Figure 3 illustrates several of the effects described above: Response speeds increased as the time limits were made more stringent (compare BL, 0.5, and 1.0); responding generally was slower when the discrimination was delayed than when it was immediate (compare columns 1 and 2); and the signal tended to reduce effects of the delay (compare columns 2 and 3). Additional findings pertain to interactions between these variables and the complexity of the sample stimulus. Figure 3 shows that when the discriminations were immediate, response speeds decreased systematically as the number of sample elements was varied from one to three. This effect became weaker as the time limit was made more stringent (most notably for Y3, Y5, and O3). The same pattern (steeper gradients under baseline than time-limit conditions) may be seen in a less consistent form when the discriminations were delayed, as well as when the delayed discriminations were signaled. The effect of the signaling procedure was to elevate the gradients to a position intermediate between the immediate and unsignaled-delay conditions.

Figure 4 presents a comparable analysis of errors. Here it may be seen that the sample element and time-limit manipulations resulted in increased errors. Moreover, effects of these variables interacted in that the element gradients became more pronounced as time limits were made more stringent (this steepening from baseline to time-limit conditions may be

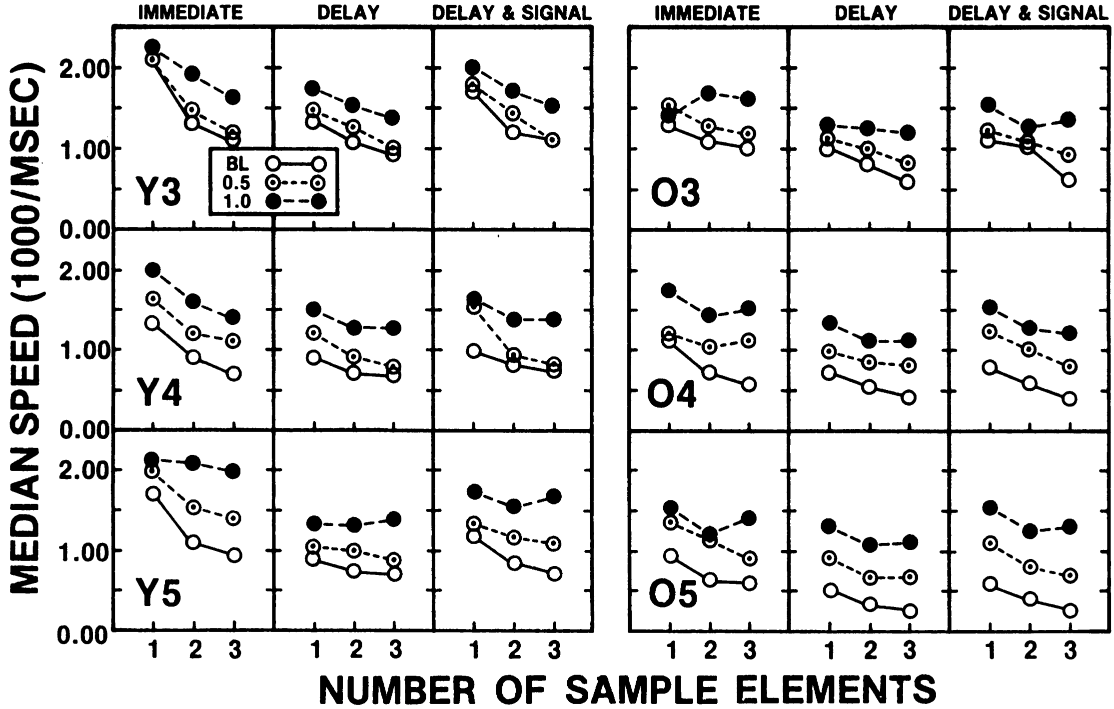

Fig. 3. Median response speeds (1000/ms) of 3 younger men (left panels) and 3 older men (right panels) as a function of the number of elements contained within the sample (1, 2, or 3). The functions within each panel show performances when there was unlimited time to respond (baseline) and when time limits were in effect (limits of 0.5 and 1.0). Individual panels summarize performances when there was no delay between the sample and choice stimuli (immediate), when the choice stimuli were delayed for 15 s (delay), and when a 2-s warning signal preceded the delayed choice stimuli (delay & signal).

seen in the majority of the panels). Figure 4 also shows a substantial number of errors under the most extreme levels of the sample element and time-limit conditions (i.e., elements = 3; time limit = 1.5). But there is no indication under these or other element-limit combinations that more errors occurred when the discriminations were delayed than when they were immediate.

Age-Related Effects

A general finding was that the younger men tended to respond more rapidly than the older ones. This effect is illustrated by Figure 1, which shows that such differences were present from the very start of the initial baseline series and that they involved all levels of the experimental variables (delay and signal). In addition, examination of performances under the time-limit conditions and during the final baseline suggests that the magnitude of age differences did not change appreciably during the course of the experiment.

To substantiate these conclusions, the baseline data before and after the time limits (BL2 and BL3) were subjected to statistical analysis. A four-factor repeated-measure design was used in which age was treated as a between-group factor and the experimental variables as within-group factors (Age × BL2-BL3 × Delay × Signal, 2 × 2 × 4 × 2). The outcomes were consistent with the impression from Figure 1. The young men generally were faster than the older men (Age, $F[1, 8] = 9.15$, $p < .025$), and increased speed from the initial baseline series to the final series was a consistent effect across the 10 subjects (BL2-BL3, $F[1, 8] = 10.22$, $p < .025$). In addition, the interaction between age and performance changes was not statistically significant (Age × BL2-BL3, $F[1, 8] = 2.02$, $p > .10$). In other words, although the baseline performances of the older men improved with exposure to the time-limit conditions, the age

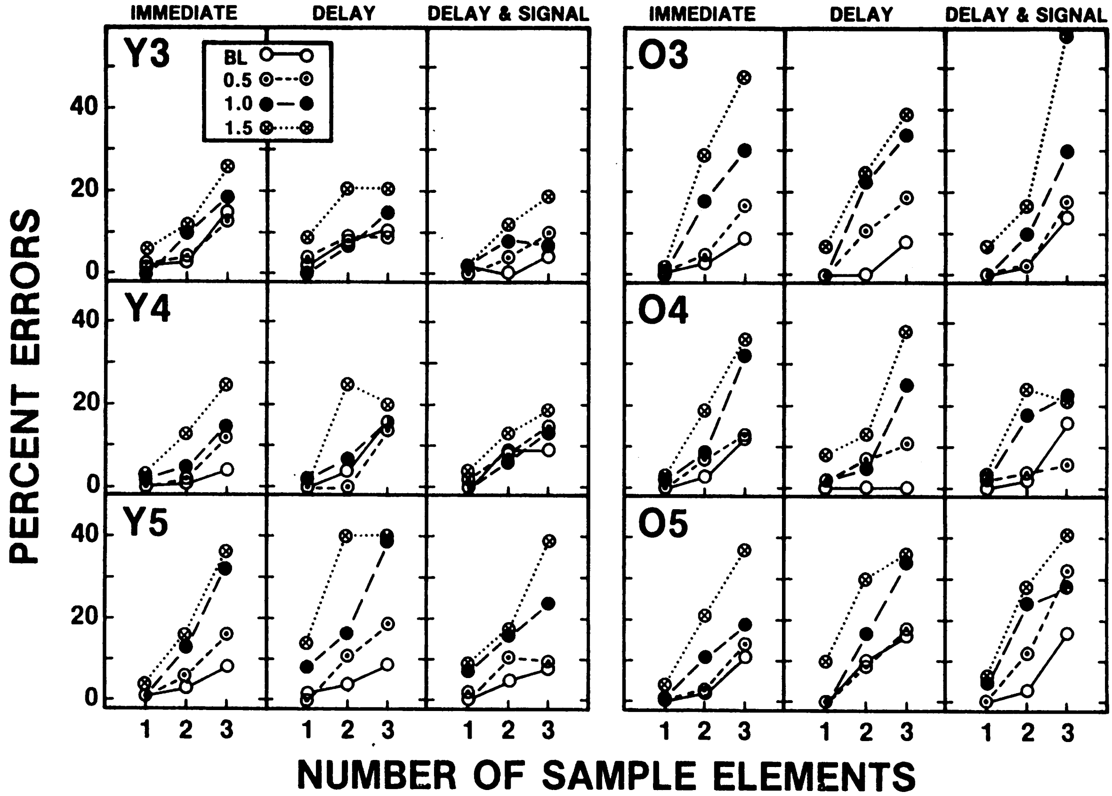

Fig. 4. Percentage of errors as a function of the number of sample elements. The data include the 1.5 time-limit condition. Other details as for Figure 3.

differences seen initially were maintained.

A different aspect of the data in Figure 1 pertains to age-dependent interactions with the delay variable. As described already, men of both ages slowed down when the discrimination was delayed. Close inspection of the figure reveals, in addition, that the delay led to larger reductions for the young men, with the consequence that age differences were reduced under the delay conditions. This interaction between age and delay together with the general effects of delay were confirmed as statistically significant effects in the analysis of variance (Delay, $F[3, 24] = 101.97$, $p < .01$; Age × Delay, $F[3, 24] = 4.18$, $p < .025$). Another feature of the age-delay interaction was that it was independent of effects correlated with signaling the discriminations or with exposure to the time limits (in both cases, the relevant higher-order interaction was not significant: Age × Delay × Signal, $F[3, 24] = 1.92$, $p > .10$; Age × Delay × Training, $F[3, 24] = 1.44$, $p > .10$).

Performance efficiency (percentage of reinforced responses) also depended on the ages of the men. A general finding, already discussed in connection with Figure 2, was that efficiency declined with increases in the severity of the limits for men of both ages. Another aspect of the data in Figure 2 was that these declines across the time limits were more marked for older than for younger men. The interaction between age and time limit was evaluated through a repeated-measure statistical analysis (Age × Limit × Signal-Delay, 2 × 3 × 3). The outcome substantiated the statistical significance of the interaction (Age × Limit, $F[2, 16] = 3.79$, $p < .05$), as well as the main effect of the time-limit variable ($F[2, 16] = 19.06$, $p < .01$).

A final age-dependent effect may be seen in the error data summarized in Figure 4. The effect of increasing the number of elements in the sample was to increase error rates for all of the men studied. Figure 4 shows that these increases were larger for the members of the older group. This conclusion also was evaluated by a repeated-measure statistical analysis

(Age × Limit × Element × Signal-Delay, 2 × 4 × 3 × 3). The results verified that the interaction between age and number of elements was statistically significant (Age × Elements, $F[2, 8] = 7.71$, $p < .025$), and also confirmed the reliability of the main effect of elements ($F[2, 8] = 154.55$, $p < .01$).

DISCUSSION

Experimental Variables

One set of findings pertained to the influences of time limits on responding. In general, responding was faster under time-limit conditions than when the men simply were instructed to respond rapidly (and temporal contingencies were absent). Increases observed with the imposition of time limits exceeded any changes during earlier practice with the discriminations (during the initial baseline series), and were manifested in conjunction with a range of other experimental manipulations. These included the extent to which the discriminations were delayed, whether or not the choice period of the delayed discriminations was signaled, and variations in the number of elements in the sample stimulus. A related finding was that increases attributable to exposure to the time limits were maintained subsequently when the time limits were removed during the terminal baseline sessions.

The facilitating effects of temporal contingencies on human response speeds have been reported previously (Baron & Menich, 1985; Baron et al., 1983). New findings, specific to the present study, pertain to performances when matching-to-sample discriminations were delayed—in particular, that responding was slower in the delayed than in the immediate discriminations. Errors in responding usually are interpreted as evidence of short-term memory loss (Roberts & Grant, 1976), and the finding that responding also is slower may be viewed in similar terms. But the results also indicate that performances were facilitated when the delayed discriminations were signaled. This finding suggests that at least some of the loss may be due to the sudden appearance of the choice stimuli. Signaling the choice period increases the likelihood that the subject is properly oriented when the stimuli are displayed, and, on this basis, the procedure might be expected to enhance performances (i.e., reduce errors as well as increase response speeds). It would be interesting to know whether the signal effects seen in the present study are generally characteristic of delayed matching-to-sample performances. However, errors rather than response speed usually are reported. (We did locate one study [Cox & D'Amato, 1982], with monkeys, that found decreased speeds as well as increased errors with increases in the sample-choice interval; so far as we know, the effects of signals on delayed matching have not been studied previously.) Among other things, the present results suggest the need to consider orienting behavior when conclusions are reached about the limits of animal memory—for example, with regard to different estimates of the memory of the pigeon depending on whether tests use matching-to-sample or delayed alternation procedures (Olson & Maki, 1983).

Another aspect of the study was the finding that response speeds depended on the number of sample elements. This relationship has a bearing on what has been termed "memory scanning" (Sternberg, 1969). The procedures of memory-scanning experiments are designed to measure the time required to identify a stimulus contained within a previously encountered list. The rate at which the individual is able to compare the current items with those previously encountered ("search short-term memory") is estimated by varying the length of the list. The assumption is that increases in the contents of the short-term memory store (in the present procedure, from one to three elements) necessitate more time for the store to be searched. When viewed in these terms, our results clearly showed this effect in that responding became slower as the number of elements was increased. But the findings with regard to the effects of the time limits suggest some needed qualifications. The implication of the results is that the inferred search rates, rather than representing a fixed capability of the individual, are under the control of the consequences of responding, and thus can vary over a broad range depending on the contingencies that are imposed. From this standpoint, performances in the absence of explicit contingencies (for example, when performances are controlled by instructions to respond rapidly—a common procedure in memory-scanning experiments) might be expected to underestimate the capability of the individual.

Although straightforward interpretations appear possible with regard to changes in response speed as a function of the experimental variables (delay, time limit, complexity), associated changes in errors introduce complications. Under the time-limit and complexity conditions, the relationship between speed and errors was systematic and predictable—that is, the relationship was a direct one across increasing time limits and an inverse one across increasing degrees of complexity. But, surprisingly, errors and speed were dissociated when the sample-choice interval was varied. Although delaying the discriminations decreased the speed of responding (Figure 3), error rates, even under conditions in which substantial errors occurred, did not show corresponding increases (Figure 4). Errors were infrequent in a previous study that used stimuli of low complexity (Baron & Menich, 1985), as well as in the one-element condition of the present experiment (see Table 2), and we reached the plausible conclusion that slower responding in delayed discriminations represents the preliminary stages of memory failure. The rationale for the present procedure was that conditions giving rise to increased errors (such as increased sample complexity) should also produce systematic error gradients as the delay interval was prolonged. Such gradients, commonly observed in studies with pigeons and monkeys, provide the strongest support for the involvement of memory processes. Moreover, as noted above, parallel changes in speed and errors have been reported in at least one study (Cox & D'Amato, 1982). Thus, the present findings with human subjects—that increased delays produced decreases in response speed but did not produce systematic increases in errors—are puzzling. Clarification must await further study.

Age-Related Effects

Inclusion of older as well as younger men in the present analysis may be viewed simply as an effort to extend the generality of the findings across subjects, a type of systematic replication (Sidman, 1960). The procedure of replicating an experiment across human subjects with different personal characteristics (e.g., social history, education, gender, developmental level) is similar to the strategy in comparative psychology of replicating experiments across species. Parallel outcomes from such replications strengthen conclusions about the generality of processes deemed basic. Alternatively, interactions between subject characteristics and experimental variables point the way to needed qualifications and modifications. Also important when the personal characteristics of human subjects are varied is that the results provide links between the experimental analysis of behavior and research pursued within more traditional areas of psychology such as, in the present case, the psychology of aging.

As noted already, numerous experiments have revealed age differences in speed performances, and such differences are frequently regarded as an inherent aspect of aging (slowing often is attributed to central nervous system deficits; Birren et al., 1980; Hicks & Birren, 1970). The strategy of the present research was to examine age differences under conditions in which the contribution of factors secondary to the aging process might be minimized. Thus, older subjects were selected who were active and in good health, data were collected when the men were well acclimated to the laboratory procedures, and performances were examined when there were explicit contingencies for rapid responding. Despite the difference of close to 50 years between the ages of the two groups of men, the striking finding was that responses to the experimental variables were considerably more similar than different. Most notably, the imposition of temporal contingencies resulted in increased response speeds to about the same extent for men of both ages. This finding, together with the results of other studies using operant procedures (Baron & Menich, 1985; Baron et al., 1983), argues against the conclusion that response slowing is an inevitable consequence of the aging process. An open question is whether increased speeds when operant contingencies are applied should be viewed as reflecting the strengthening of otherwise unpracticed repertoires (Thorndike, Bregman, Tilton, & Woodyard, 1928) or the development of mechanisms that compensate for central nervous system inadequacies. In either case, the present procedures illustrate the feasibility of using operant contingencies to modify slow responding of older adults.

The notion that behavioral deficits associated with age result from insufficient exposure to appropriate contingencies has been termed the "disuse hypothesis" (see Thorndike et al., 1928). As noted elsewhere (Baron & Menich, 1985), this hypothesis has two implications: first, that performance deficits in older adults can be reversed (or at least retarded) through appropriate training procedures; and second, that such training should bring performances of older adults closer to the levels of equivalently trained younger adults. The present findings provide good support for the first of these predictions, but there was no indication in the results that age differences, seen at the start of the experiment, were reduced as a consequence of the training procedures. This pattern of results is not unlike that of several other negative tests of the disuse hypothesis (for a review, see Kausler, 1982). But various arguments still can be adduced in defense of the hypothesis—particularly that procedures of previous studies may not have been optimal. Although the procedures reported here were designed to improve upon those of previous research, it remains to be seen whether yet more intensive training combined with more sensitive schedules might bring older adults closer to the levels of younger individuals.

The experimental variables of the present study have also been examined by other researchers in the field of aging, in work that usually has been pursued within a cognitive framework. We found that although the older men typically were slower in their responses, differences from the younger men did not increase when the discriminations were delayed (if anything, differences decreased; for similar results, see Baron & Menich, 1985). This finding can be viewed as consistent with a body of literature indicating that short-term memory does not change in major ways with advancing age (Kausler, 1982; but see Inman & Parkinson, 1983). By comparison, the present results appear contrary to the hypothesis that older individuals require more time to prepare for upcoming stimuli (Welford, 1977). Although our use of a warning signal improved the performances of older men, there was no indication that the older men benefited more from advance notice of the discriminations than did their younger counterparts. The present results support two other generalizations about aging: that older individuals are at a progressively greater disadvantage when they must respond under conditions of increasing time pressure (Welford, 1977), or to tasks of increasing complexity (Cerella et al., 1980). Our findings in these regards were consistent in that the older men's efficiency (success in obtaining the reinforcers) deteriorated more rapidly as the time limits were made more stringent, and that the older men made disproportionate numbers of errors as sample complexity was increased.

Thus, it may be seen that the present analysis of age differences, although emphasizing steady-state methodology and reinforcement variables, touches upon current areas of concern within the field of aging. Experimental research on aging characteristically has used group-statistical designs and the concepts of cognitive psychology. Our study illustrates the feasibility of an alternate approach based on the procedures and the concepts of the experimental analysis of behavior.

REFERENCES

Baron, A., & Menich, S. R. (1985). Age-related effects of temporal contingencies on response speed and memory: An operant analysis. *Journal of Gerontology*, **40**, 60-70.

Baron, A., Menich, S. R., & Perone, M. (1983). Reaction times of younger and older men and temporal contingencies of reinforcement. *Journal of the Experimental Analysis of Behavior*, **40**, 275-287.

Baron, A., & Perone, M. (1982). The place of the human subject in the operant laboratory. *Behavior Analyst*, **5**, 143-158.

Birren, J. E., Woods, A. M., & Williams, M. V. (1980). Behavioral slowing with age: Causes, organization, and consequences. In L. W. Poon (Ed.), *Aging in the 1980s* (pp. 293-308). Washington, DC: American Psychological Association.

Cerella, J., Poon, L. W., & Williams, D. M. (1980). Age and the complexity hypothesis. In L. W. Poon (Ed.), *Aging in the 1980s* (pp. 332-340). Washington, DC: American Psychological Association.

Church, R. M., & Camp, D. S. (1965). Change in reaction-time as a function of knowledge of results. *American Journal of Psychology*, **78**, 102-106.

Cox, J. K., & D'Amato, M. R. (1982). Matching to compound samples by monkeys (*Cebus apella*): Shared attention or generalization decrement? *Journal of Experimental Psychology: Animal Behavior Processes*, **8**, 209-225.

Hicks, L. H., & Birren, J. E. (1970). Aging, brain damage, and psychomotor slowing. *Psychological Bulletin*, **74**, 377-396.

Inman, V. W., & Parkinson, S. R. (1983). Differences in Brown-Peterson recall as a function of age and retention interval. *Journal of Gerontology*, **38**, 58-64.

Johanson, A. M. (1922). The influence of incentive and punishment upon reaction time. *Archives of Psychology*, No. **54**, 1-53.

Kausler, D. H. (1982). *Experimental psychology and human aging*. New York: Wiley.

Kimble, G. A. (1961). *Hilgard and Marquis' Conditioning and learning* (2nd ed.). New York: Appleton-Century-Crofts.

Moody, D. B. (1970). Reaction time as an index of sensory function. In W. C. Stebbins (Ed.), *Animal psychophysics* (pp. 277-302). New York: Appleton-Century-Crofts.

Olson, D. J., & Maki, W. S. (1983). Characteristics of spatial memory in pigeons. *Journal of Experimental Psychology: Animal Behavior Processes*, **9**, 266-280.

Perone, M., & Baron, A. (1983). Reduced age differences in omission errors after prolonged exposure to response pacing contingencies. *Developmental Psychology*, **19**, 915-923.

Roberts, W. A., & Grant, D. S. (1976). Studies of short-term memory in the pigeon using the delayed matching to sample procedure. In D. L. Medin, W. A. Roberts, & R. T. Davis (Eds.), *Processes of animal memory* (pp. 79-112). Hillsdale, NJ: Erlbaum.

Salthouse, T. A., & Somberg, B. L. (1982). Skilled performance: Effects of adult age and experience on elementary processes. *Journal of Experimental Psychology: General*, **111**, 176-207.

Saslow, C. A. (1968). Operant control of response latency in monkeys: Evidence for a central explanation. *Journal of the Experimental Analysis of Behavior*, **11**, 89-98.

Saslow, C. A. (1972). Behavioral definition of minimal reaction time in monkeys. *Journal of the Experimental Analysis of Behavior*, **18**, 87-106.

Sidman, M. (1960). *Tactics of scientific research*. New York: Basic Books.

Sidman, M. (1969). Generalization gradients and stimulus control in delayed matching-to-sample. *Journal of the Experimental Analysis of Behavior*, **12**, 745-757.

Stebbins, W. C. (1962). Response latency as a function of amount of reinforcement. *Journal of the Experimental Analysis of Behavior*, **5**, 305-307.

Stebbins, W. C. (1966). Auditory reaction time and the derivation of equal loudness contours for the monkey. *Journal of the Experimental Analysis of Behavior*, **9**, 135-142.

Sternberg, S. (1969). Memory-scanning: Mental processes revealed by reaction-time experiments. *American Scientist*, **57**, 421-457.

Thorndike, E. L., Bregman, E. O., Tilton, J. W., & Woodyard, E. (1928). *Adult learning*. New York: Macmillan.

Welford, A. T. (1977). Motor performance. In J. E. Birren & K. W. Schaie (Eds.), *Handbook of the psychology of aging* (pp. 450-496). New York: Van Nostrand Reinhold.

Welford, A. T. (Ed.). (1980). *Reaction times*. New York: Academic Press.

Received December 16, 1984
Final acceptance April 27, 1985