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REACTION TIMES OF YOUNGER AND OLDER MEN AND TEMPORAL CONTINGENCIES OF REINFORCEMENT

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Influences of extended training and temporal contingencies on reaction time were studied in relation to developmental differences. Older and younger men were trained on a chained schedule in which completion of a variable interval produced a terminal link in which reaction time was measured. The reaction-time procedure involved a conditional discrimination with matching to sample in one component and oddity matching in the other. During baseline training, no time limit was placed on the response to the discrimination choice stimuli. Subsequently, increasingly severe time limits were imposed over a series of sessions. Older and younger men showed increased speeds (decreased reaction times) when temporal contingencies were imposed, and these changes were maintained during post-training baseline sessions when there was unlimited time in which to respond. The younger men generally responded faster than the older ones, and age differences were not appreciably reduced during the course of the experiment. The results indicated the feasibility of studying reaction time in human subjects using operant procedures analogous to those developed for the study of nonverbal organisms.

Key words: reaction time, practice effects, chained schedule, matching to sample, oddity matching, young and old adult humans

Although speed of responding was one of the first subjects of inquiry by early experimental psychologists (see Woodworth & Schlosberg, 1954), this property of behavior has not received much attention by operant psychologists. Procedures for studying reaction time have remained more or less unchanged for the past 100 years. In the simplest version, a human subject is instructed to hold a key down in response to a ready signal and to release it when a stimulus (e.g., a tone or light) is presented. The time between onset of the stimulus and release of the key is taken as the reaction time for that trial.

Stebbins and Lanson (1961) pointed out that the reaction-time procedure can be construed as a two-link chain schedule. Holding the key down in the initial link produces the terminal link where release of the key in response to the stimulus is reinforced. They adapted this procedure to study reaction time in rats. The subjects were trained to hold down a lever when a light (ready signal) was presented. Holding the lever for 2 sec produced a tone, and release of the lever in the presence of the tone was reinforced. Reaction times decreased with increases in reinforcer magnitude (Stebbins, 1962) and frequency (Stebbins & Lanson, 1962). Subsequent research with rats and monkeys (Miller, Glickstein, & Stebbins, 1966; Moody, 1970; Saslow, 1968, 1972; Stebbins, 1966) showed that reaction times also vary as a function of stimulus characteristics (intensity, frequency) and contingencies for rapid responding (reinforcement occurred only if the response was within a time limit).

It is instructive to compare Stebbins' operant procedure, developed to investigate animal behavior, with the traditional procedures followed with human subjects. In the case of animals, motivation is controlled through deprivation, and rapid responding is differentially reinforced. By comparison, measurement of human reaction time relies heavily on instruction ("hold the key down and release it

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when the stimulus occurs") and exhortation ("respond as rapidly as you can"), and no explicit contingencies reinforce rapid responding (e.g., there is no standard procedure concerning provision of feedback). Another procedural difference concerns the consequences of releasing the lever prior to onset of the stimulus (foreperiod responses). The animal subject is penalized by termination of the trial and loss of opportunity to gain reinforcement, whereas the human subject is reprimanded ("please do not lift the key before the stimulus is presented"). Perhaps most critical is that animal reaction times have been studied in individual organisms as a steady-state phenomenon, with measurements taken only after extended training. By comparison, most research with human subjects focuses on average performances of groups of subjects performing on a limited series of trials usually completed during a single session.

Operant procedures allow reaction time to be studied independently of the contribution of instructions or other types of verbal interventions. As noted by Stebbins and Lanson (1961), an operant analysis of reaction time has the additional virtue of focusing on the functional realtionship between a response and its controlling variables. Although these methods would appear to have merit for the study of reaction time in human subjects, systematic analyses have not been reported. However, a few experiments may be cited in which the procedures included some of the elements of the animal research, such as extended training (e.g., Murrell, 1970; Salthouse & Somberg, 1982) and specific contingencies for rapid responding (e.g., Church & Camp, 1965; Snodgrass, Luce, & Galanter, 1967). The finding that these procedures influenced reaction time (generally, times were reduced) suggests that further study along these lines would be worthwhile.

The present investigation with human subjects is based on a procedure used in an experiment with monkeys by Miller et al. (1966). They progressively limited the time available to respond from session to session (latencies longer than the time limit were not reinforced) and found substantial decreases in reaction time as a consequence (about 40% in one animal and 30% in another). We followed parallel procedures, but, in addition, we examined the effects of extended training and time limits as a function of certain personal characteristics of the human subjects, namely, their ages.

We have discussed elsewhere the importance of considering those variables traditionally termed "individual differences" when operant research is conducted with humans (Baron & Perone, 1982). Concerning reaction time, a well known finding is that speed of responding is impaired in older adults (Birren, 1974). Such deficits have been reported not only for the reaction-time task (both simple and disjunctive) but also for more complex types of behavior such as those described in the traditional literature on recognition memory, verbal learning, and performance subtests of standard intelligence scales (Kausler, 1982). The most popular interpretation of these findings is that decreased speed of responding reflects changes in the central nervous system that are more or less irreversible. Alternative views are possible, however. For example, with increasing age, individuals are increasingly exposed to environments that do not demand or reinforce rapid responding. Further, older adults may be less familiar with laboratory procedures than college-age subjects, and performance evaluations may evoke competing emotional responses that bias short-term assessments of behavior. Comparisons of young and old adults using steady-state research designs and explicit contingencies for rapid responding should help clarify the extent to which age-related deficits are subject to change through environmental manipulation.

Cerella, Poon, and Williams (1980) suggested that older adults are at an increasing disadvantage as the complexity of speeded tasks is increased. This consideration led us to study speed of responding to complex discriminations: older and younger men responded to a series of conditional discriminations with matching to sample in one component and oddity matching in the other.

METHOD

Subjects

Seven younger men (mean age = 20.3 yr, range = 18 to 23) and seven older men (mean age = 69.7 yr, range = 63 to 79) 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 men were undergraduate students and the older were participating in a course-audit program for older adults. According to a self-administered medical questionnaire, all were in good health and none had been hospitalized during the past year. Performances on selected subtests of the Wechsler Adult Intelligence Scale placed them at or above average levels for the general population.

After a preliminary session, the men gave informed consent to participate in the research by signing a contract to serve for at least 40 hr scheduled over 2 to 4 weeks. To ensure completion of the project, payment included a bonus of $2.00 per hr dependent on completing the experiment. This bonus was in addition to money that could be earned during the experimental sessions ($2.00 per hr, maximum). They also received compensation for travel expenses based on the prevailing round-trip bus fare.

Apparatus

Each man sat at a table in a sound-attenuated room, 1.8-m square. A console on the table contained a 12-in. (31-cm) video monitor for presenting white visual stimuli on a dark screen, two telegraph keys for measuring reaction times, and a pushbutton. The center of the monitor screen was approximately 45 cm above the table top. The knobs of the telegraph keys protruded 2 cm from the left and right sides of the base. Excursion of the keys, when pressed or released, was approximately 1 cm. When a man was seated at the table, the screen was at eye level, approximately 50 cm away, and the two telegraph keys were at arms' length. Mounted under the table directly to the man's right was a spring-loaded Lindsley-type plunger (Gerbrands, No. G6310), which operated if pulled a distance of 2.5 cm with a force of at least 2 lb (about 9 N). A speaker on the right wall delivered auditory stimuli. Control and recording equipment in a nearby room included a microcomputer (Tandy Corp., TRS-80), an interface between the computer and the subject's console (LVB Corp.), and accessory electromechanical components.

Procedure

General procedure. The basic schedule was a two-link chain: pulling the plunger in the first link gained entry into the second, reaction-time link. Choice reaction times were measured in the second link, using operation of the telegraph keys as the response and characters displayed on the screen as the stimuli (e.g., the letter "A"; the number "3"; or the symbol "#"). The procedure was arranged as a matching-to-sample discrimination: A sample stimulus was presented for inspection followed by two choice stimuli, one of which could be selected by operating the corresponding telegraph key.

In the initial link of the schedule, each plunger pull produced a brief feedback stimulus (.2-sec asterisk) in the center of the screen. Plunger responses also produced the second link of the chain according to a variable interval 15-sec schedule (range = 1 to 56 sec). When the variable interval requirement was met, the reaction time component began: The plunger was deactivated, a 5-kH tone sounded for .3 sec from the speaker, and the message "Hold the keys down" appeared on the screen. As soon as both telegraph keys were depressed (the men were instructed to use their forefingers), the sample stimulus was displayed in the center of the screen for 2 sec (the "foreperiod") during which time it was necessary to hold the keys in the depressed position. Upon termination of the sample, the two test stimuli, one the same as the sample and the other different, appeared on the left and right sides of the screen. The subject responded by releasing one of the two keys. Immediately upon release a message on the screen indicated whether the response was "Right" or "Wrong" and the pushbutton on the base of the console was lit. Pressing the button terminated the light and sounded a 1-sec 1-kH tone accompanied by either of two messages: "You have gained 1 credit" if the choice was correct, or "You have lost 0 credits" if the choice was incorrect (for the first pair of subjects, but not thereafter, the message read "You have lost 1 credit" following an incorrect choice). After a 1-sec delay when the screen was blank, the initial link of the schedule was reinstated.

The correct responses in the terminal reaction-time link depended on a message displayed during the initial link. If the message was "Problem: Same," reinforcement was contingent on release of the key corresponding to the stimulus that matched the sample. If the message was "Problem: Diff," the contingency required release of the key corresponding to the stimulus that differed. Thus, the reaction-time link included a conditional discrimination with equiprobable matching-to-sample and oddity-matching components. The conditional stimuli (the messages "same" or "different") were displayed continuously throughout the initial link but were absent during the reaction-time link (they were terminated as soon as the telegraph keys were depressed).

Additional contingencies within the reaction-time link penalized responses during the 2-sec period when the sample was displayed (foreperiod responses) and release of more than one key during the choice period. Foreperiod responses produced the message "You released the keys too soon" for 2 sec, and the schedule reverted to the initial link. Release of both keys during the choice period was treated as an error and produced the message "Wrong, you released both keys." Foreperiod and two-key responses were infrequent during the course of the experiment, usually occurring on 5% or fewer of the trials.

Each credit was worth 1.75 cents. At the end of the session, the amount of money that had been earned was displayed on the screen. The subject was provided with a receipt before leaving the laboratory, but actual monetary payment was delayed until the end of the subject's participation.

Instructions. Instructions included printed material, as well as the various messages presented on the screen. Essential features of the instructions 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" worth money.
(d) Following the message, "Problem: Same," the correct stimulus is the one that is the same as the previous sample, and following the message, "Problem: Diff," the correct stimulus is the one that is different.
(e) "To operate the apparatus properly, you must release only one key per trial," and "if you release the key before the test stimuli appear, the trial will end automatically."
(f) "To maximize your earnings you must be both accurate and prompt."
(g) At first, "you will have unlimited time in which to choose. During subsequent sessions, you will be required to select the correct test stimulus within a time limit."
(h) "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."

Experimental conditions. Table 1 gives the sequence of conditions to which each man was exposed. During the baseline phases, unlimited time was available in which to respond to the choice stimuli. Under the training conditions, time limits were introduced so that responses occurring beyond a criterion duration were not followed by the credit message. Instead, the message "You released the keys too late" appeared on the screen, followed, after 2 sec, by the initial link in which plunger pulling was required to produce another reaction time trial.

Although all of the men were exposed to a common sequence of conditions, several aspects of the procedure were varied as the ex-

Table 1

Sequence of baseline (BL) and training (Train) conditions and number of sessions under each.

Man[a]	*Age*	*BL-1*	*Train-1*	*BL-2*	*Train-2*	*BL-3*
Y1	21	1[b]	24	6	7	—
Y2	21	1[b]	16	7	11	—
Y3	19	9	12	9	5	—
Y4	21	9	15	12	—	—
Y5	23	9	11	10	5	—
Y6	19	5	14	2	12	2
Y7	18	5	14	2	12	2
O1	66	1[b]	24	6	7	—
O2	66	1[b]	16	8	8	—
O3	63	11	10	8	6	—
O4	76	10	13	6	6	—
O5	65	9	16	5	5	—
O6	79	5	14	2	12	2
O7	73	5	14	2	12	2

[a]Y = Young, O = Old; men with the same subject number comprised a pair.
[b]Initial baseline not stable.

periment progressed. When such variations were introduced, a pair of men, one young and one old, was treated similarly. The most significant procedural variation involved the system for reducing the time limits from session to session. In the case of Pairs 1 to 5 a modified shaping procedure was followed that based the reductions on each individual's reaction times during previous sessions. By comparison, Pairs 6 and 7 were observed with a fixed set of values, and time limits were reduced progressively over sessions regardless of reaction times.

The shaping procedures used with Pairs 1 to 5 set the initial time limit at the 80th centile of the distribution of latencies produced by the subject during the previous baseline session. As latencies decreased, the limit was reduced to the 80th centile of the immediately preceding training session. (For the members of Pair 1, these limits were based on the pooled latencies for both matching and oddity discriminations; when it became apparent that reaction times differed depending on the type of discrimination, the limits were adjusted separately for Pairs 2 to 5.) A reduction in the time limit also required that at least 90% of responses made within the limit were correct. But if this criterion was not met after three sessions with a given limit, the limit was reduced regardless of errors so long as the 80th centile was less than the previous limit. This shaping procedure was continued until there were no further decreases in latency, at which point the baseline procedures were reinstated. As indicated in Table 1, additional baseline sessions and a second descending series of paced sessions were conducted as time permitted.

The procedures followed with Pairs 6 and 7 were designed to expose the men to a common series of time limits. Following the baseline phase, the initial time limit for both discriminations was set at 800 msec and then progressively reduced with two sessions conducted at each value. The limits were treated as speeds (i.e., 1000/latency = responses/sec) and reduced in equal steps: 1.25 responses/sec (800 msec), 1.50 (667 msec), 1.75 (571 msec), 2.00 (500 msec), 2.25 (444 msec), 2.50 (400 msec), and 2.75 (364 msec). As with the other subjects, a second series of observations followed.

Another difference pertains to instructions. As indicated above, all subjects were instructed at the start that time limits would be introduced subsequently, and no further information was provided Pairs 1 to 5. Thus, contact with the time limits during training sessions and contact with withdrawal of the contingencies during baseline sessions depended on the men's response speeds as well as the scheduled condition. To facilitate contact with the changed contingencies, members of Pairs 6 and 7 were given the following additional instructions. When conditions changed from baseline to training, they read, "Up to this point you have had an unlimited time to choose which key to release, but beginning today there can be a time limit." When conditions were changed from training to baseline, they read "For many sessions you have had a limited amount of time to choose the correct key . . . [but] . . . from now on, the time limit will be removed from the procedure so that you will have as much time as you wish. Although there is no longer a time limit, it is still true that you can maximize your earnings by responding promptly."

RESULTS

Analyses summarized in Table 2 and Figures 1 to 4 are concerned with responding in the terminal, reaction-time link of the chain. Additional data pertaining to the plunger response in the initial link are presented in Table 3.

On the assumption that increasing weight should be given to latency changes as latencies decreased, reaction times were converted to speeds (i.e., 1000/latency = responses/sec). This transformation has the further advantage of reducing the positive skew that characterizes latency distributions and allows use of the mean to summarize performances.

Results for the first six men (Pairs 1 to 3) are summarized in Table 2, which shows speeds (*S*) and percent errors (*E*, releasing the wrong key) during the series of shaped training sessions. (Because the exact time limits differed from subject to subject, response speeds and errors are tabled as a function of classes of speed limits; when there was more than one exposure to values within a given class, the fastest speed in the class is given.) Data for the other eight men are shown graphically in

Figure 1 (Pairs 4 and 5, shaping procedure) and Figure 2 (Pairs 6 and 7, fixed time limits), with speeds in the left panels and errors in the right panels. The table and figures provide separate values for matching-to-sample and oddity-matching discriminations (in Table 2: (S)ame vs. (D)ifferent; in Figures 1 and 2: unfilled circles vs. filled circles). Each entry is the mean of approximately 50 trials, that is, all data collected during the terminal session under a given training condition. Pre- and post-training baseline (BL) values also are shown: The first set represents performances during the initial baseline session, and the subsequent values during the terminal baseline session following training.

The data show that response speeds increased progressively as the more stringent time limits were imposed. Additionally, changes induced by the training procedures were maintained when the time-limit contingency was removed (compare BL1 and BL2). There were no further improvements during the second training series (not shown), nor additional changes in subjects exposed to the baseline procedure a third time (Pairs 6 and 7). Finally, this general pattern of results char-

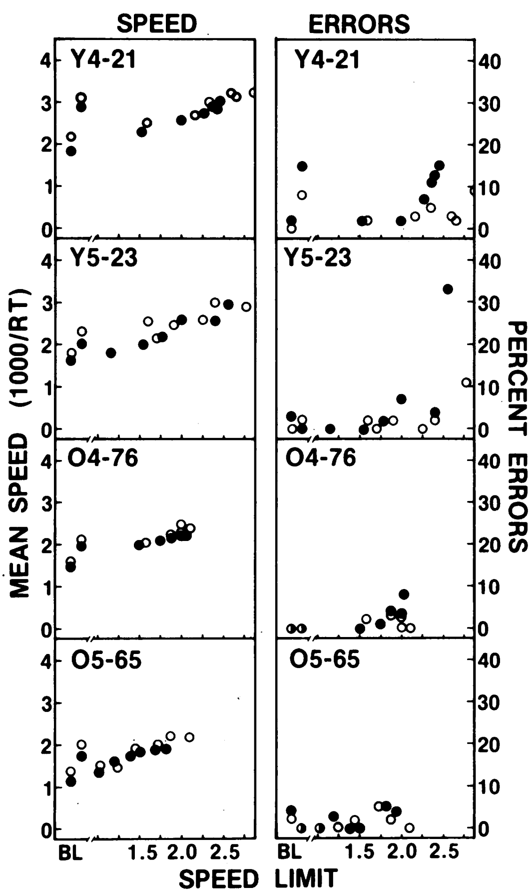

Fig. 1. Response speed (left panels) and percent errors (right panels) as a function of speed limit (1000/RT). Data are from two younger and two older men observed with the shaping procedure. Unfilled circles represent performances on matching-to-sample discriminations and filled circles on oddity-match discriminations. Each point is the mean of all trials (approximately 50) conducted during a single session with a given limit. Also shown are data from baseline (BL) sessions conducted before training (first point) and after the training series.

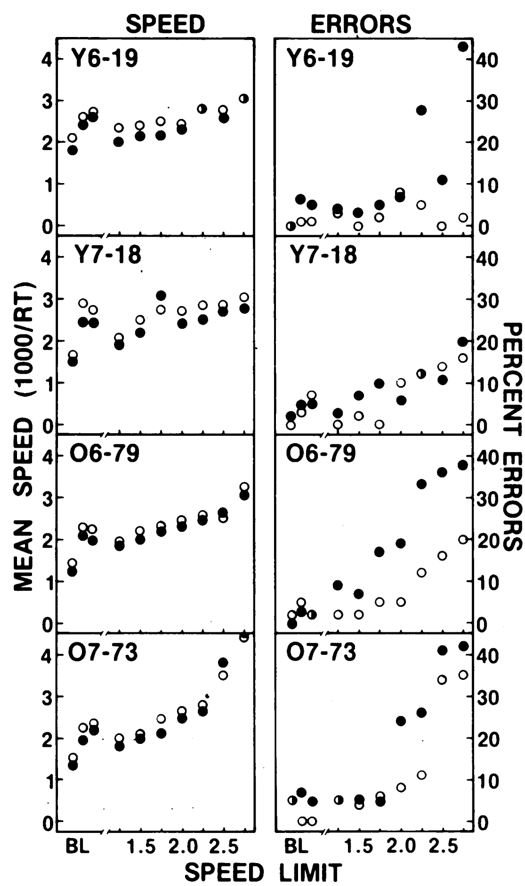

Fig. 2. Response speeds (left panels) and percent errors (right panels) as a function of speed limit (1000/RT). Data are from two younger and two older men observed with a common set of decreasing time limits. Each point is the mean of all trials (approximately 50) conducted during the second of the two sessions with each of the limits. Other details as in Figure 1.

Table 2

Mean response speeds and percent errors. The training conditions are grouped in .25 speed limit classes. Performances are shown for matching-to-sample discriminations (Same, *S*) and oddity matching (Different, *D*). Response speeds and errors in the initial baseline (BL1) and the last posttraining baseline (BL2) sessions.

		Younger Men						*Older Men*					
		Y1		*Y2*		*Y3*		*O1*		*O2*		*O3*	
Speed Limit		*Speed*	*%E*	*Speed*	*%E*	*Speed*	*%E*	*Speed*	*%E*	*Speed*	*%E*	*Speed*	*%E*
BL1	S	2.12	3	1.70	0	1.71	2	1.74	0	1.18	0	2.14	2
	D	2.04	3	1.30	0	1.54	1	1.53	0	1.03	2	1.77	2
0.75-0.99	S	—	—	—	—	—	—	—	—	1.39	0	—	—
	D	—	—	—	—	—	—	—	—	1.21	2	—	—
1.00-1.24	S	—	—	—	—	—	—	—	—	1.73	0	—	—
	D	—	—	2.06	2	—	—	—	—	1.69	2	—	—
1.25-1.49	S	—	—	2.32	5	—	—	2.13	0	—	—	—	—
	D	—	—	—	—	1.97	8	1.89	2	—	—	—	—
1.50-1.74	S	—	—	—	—	2.22	6	—	—	1.90	0	—	—
	D	—	—	—	—	—	—	—	—	1.83	13	—	—
1.75-1.99	S	2.48	0	2.52	2	2.34	13	2.34	0	2.18	0	2.41	0
	D	2.32	0	2.37	6	2.24	4	2.08	7	—	—	2.39	2
2.00-2.24	S	2.68	0	—	—	2.47	8	2.31	2	—	—	2.56	5
	D	2.56	3	3.09	10	2.28	11	2.16	7	—	—	2.38	4
2.25-2.49	S	2.70	0	3.28	13	2.54	8	—	—	—	—	2.63	3
	D	2.63	0	3.27	22	—	—	—	—	—	—	—	—
2.50-2.74	S	2.96	0	2.91	3	—	—	—	—	—	—	—	—
	D	2.74	6	—	—	—	—	—	—	—	—	—	—
BL2	S	2.56	0	2.17	0	2.54	8	2.27	6	2.17	2	2.47	0
	D	2.41	2	1.75	1	2.33	22	2.04	5	1.92	9	2.38	0

acterized both matching-to-sample and oddity-matching discriminations, although matching-to-sample speeds tended to be somewhat faster.

The more severe time limits also resulted in increased errors. This is particularly apparent for Pairs 6 and 7 who were trained with the procedure in which the time to respond was progressively reduced regardless of errors. With some exceptions, more errors were made in response to the oddity-matching discriminations than to the matching-to-sample discriminations.

Figure 3 addresses the question of whether response speeds varied as a function of the men's ages. In each case, a maximal speed was determined based on the most stringent limit that could be tolerated (at least 80% of responses within the limit) with an error rate less than 20%. The points in the right panels of Figure 3 (Training 1 and Training 2) show each man's maximal speed on the two kinds of discriminations (younger men, filled circles; older men, unfilled circles), with matching to sample ("same") scaled on the abscissa and oddity matching ("different") on the ordinate. Thus, faster matching-to-sample speeds are shown by points below the diagonal and faster oddity-matching speeds by points above the diagonal. Similar data for the baseline conditions are given in the left panels (Baseline 1 and Baseline 2).

Figure 3 shows that the younger men responded faster than the older ones during Baseline 1, but there also were noteworthy exceptions (e.g., Y2, age 21 yr, who fell within the distribution of the older men and O3, age 63 yr, who fell within the distribution of younger ones). The training procedures shifted the distributions in the direction of faster speeds (Training 1), and these gains were maintained to some extent during the second baseline series (Baseline 2). Additional training (Training 2) replicated the previous fast speeds, but generally there were no further improvements. Also apparent is that although this pattern of change was manifested for both types of discrimination, response speeds were consistently faster for matching to

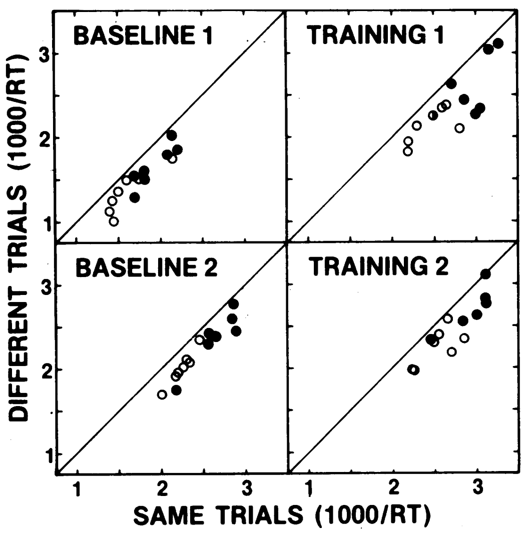

Fig. 3. Maximal response speeds of older men (unfilled circles) and younger men (filled circles). Each point represents performance for a given subject on the two types of discrimination with matching to sample ("same") scaled on the abscissa and oddity matching ("different") scaled on the ordinate. Performances during the baseline phases are shown in the left panels (Baseline 1 and Baseline 2) and during the training phases in the right panels (Training 1 and Training 2). Values are based on contingencies under which at least 80% of the responses fell within the limit and the error rate was equal to or less than 20%.

sample (virtually all points are below the diagonals).

As noted above, the younger men responded more rapidly than the older ones during the various phases of the experiment, but the two age distributions overlapped sufficiently to raise questions about the reliability of differences and whether they were reduced through training. To evaluate these effects, statistical procedures (analysis of variance) were used to analyze the following variables: Age (Young vs. Old), Condition (Baseline vs. Training), Replication (1 vs. 2), and Type of Discrimination (matching to sample vs. oddity matching). (Subject Y4, who did not participate in the second replication, was excluded from the analysis.) The statistical analysis generally supported the conclusions drawn from inspection of Figure 3. Thus, by comparison with baseline performances, training produced faster speeds in both replications (Condition, $F(1,11) = 58.67$, $p < .01$), although to a diminished extent during the second time (Condition × Replication, $F(1,11) = 85.89$, $p < .01$). Throughout, the responses of the older men were slower than those of the younger ones (Age, $F(1,11) = 15.00$, $p < .01$). The analysis provided no support for the hypothesis that training reduced the age differences seen initially (Age × Condition, $F(1,11) = .71$, $p > .05$; Age × Condition × Replication, $F(1,11) = 0.27$, $p > .05$). The older and younger men improved equally, with the consequence that the initial difference was maintained throughout the experiment.

The above analyses were based on mean speeds for entire sessions (approximately 50 trials for each type of discrimination) and do not reflect variation within the sessions. The extent of such variation may be expressed in terms of *C*, the coefficient of variation (the ratio of the standard deviation to the mean). The median value of *C* across subjects and conditions (see data depicted in Table 2 and Figures 1 to 3) was approximately 15% for the younger men and 16% for the older men, with most of the values falling between 10% and 20%.

A more detailed picture of within-session variation is provided by Figure 4, which shows selected response-speed distributions for the last pair of men (Y7, age 18 yr; 07, age 73 yr). The distributions, based on matching-to-sample performances for entire sessions, are organized sequentially, from left to right: initial and terminal performances during the first baseline series (shaded), the first training series (unshaded), the second baseline series (shaded), and the second training series (unshaded).

Aside from providing information about typical characteristics of the response-speed distributions (generally they were symmetrical about a single mode), Figure 4 makes it clear that increased speeds resulting from training involved shifts in the entire distributions. The overall modification in responding may be seen by comparing the broken line, the mean of the first distribution, and the solid line, the mean of the last distribution. Also noteworthy is the extent of overlap between the distributions, both from the standpoint of performances of a given individual from condition to condition (e.g., from baseline to training), and the performances of different individuals (i.e., the younger and older men). These patterns of variation indicate the need to qualify interpretation of differences associated with training condition and age. Although the men generally responded faster as each new time limit was imposed, some of the speeds were no faster than was the case with less severe limits. Further, although the older men generally were slower than the younger ones in their mean speeds, a substantial proportion of responses by older men fell well within the distributions of the younger ones.

Table 3 summarizes performances in the first link of the chain: the rate at which the plunger was pulled and the amount of time elapsing between the end of the reinforcement cycle and the first response in the subsequent initial link of the chain (i.e., the postreinforcement pause). A comparison of baseline and training values indicates that the severity of the temporal contingency in the second link of the chain did not systematically influence performances in the initial link. Further, responding in the initial link was not a clear function of the age of the subject. The main difference in this regard was during the initial baseline phase, during which the older men tended to respond at lower rates and to pause longer after reinforcement than the younger ones (some exceptions to this pattern also may be seen in Table 3). However, these differences were not maintained during subsequent phases of the experiment.

Table 3

Rates of plunger pulling and duration of postreinforcement pausing under baseline (BL) and training (TR) conditions.

	Plunger Rates (Resp/min)				*Postreinforcement Pause (sec.)*			
Man[a]	*BL* (*1*)	*TR* (*1*)	*BL* (2)	*TR* (2)	*BL* (*1*)	*TR* (*1*)	*BL* (2)	*TR* (2)
Y1	59	50	36	35	.80	.45	.95	.80
Y2	141	111	126	102	.25	.20	.20	.35
Y3	60	89	78	110	.45	.55	.45	.25
Y4	111	126	—	—	.30	.25	—	—
Y5	16	9	11	13	1.25	3.85	2.65	3.05
Y6	144	116	132	138	.30	.30	.20	.25
Y7	111	95	96	60	.35	.40	.30	.55
Median	111	95	87	81	.35	.40	.38	.45
O1	36	58	63	64	.95	.55	.30	.30
O2	12	18	56	50	6.00	5.85	1.35	.95
O3	112	96	124	118	.30	.30	.30	.20
O4	122	107	110	114	.20	.20	.20	.15
O5	43	124	114	106	2.00	.45	2.90	2.40
O6	47	56	56	60	1.20	.80	.75	.55
O7	112	145	144	162	.85	.50	.45	.40
Median	47	96	110	106	.95	.50	.45	.40

[a]Y = Young; O = Old.

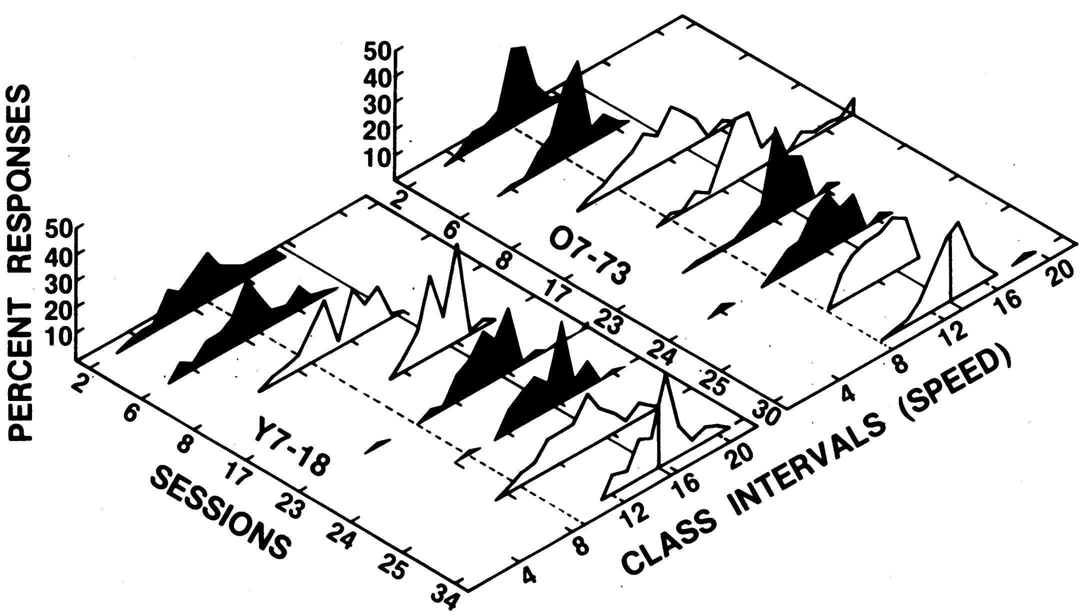

Fig. 4. Within-session response-speed distributions for a younger and an older subject. Each distribution summarizes the proportion of matching-to-sample responses falling into a given class of response speeds. The conditions from left to right are: first baseline series (shaded), first training series (unshaded), second baseline series (shaded), and second training series (unshaded). The broken line represents mean response speed during the initial session of the experiment; the solid line, mean response speed during the terminal session.

DISCUSSION

The present experiment studied reaction time in human subjects from the standpoint of temporal contingencies, in preference to the less clear control that may be exerted by instructions and exhortations (e.g., "respond quickly and accurately"). In addition to showing the importance of reinforcement mechanisms in determining response speed, the data clarify interactions between temporal contingencies and the ages of the subjects. These two aspects of the results are discussed below.

Reinforcement of Rapid Responding

Speeds increased when reinforcement required that the response occur within a specified period of time. Although increased speeds were accompanied by increased errors, particularly at the most severe time limits, all of the men, regardless of age, were capable of responding efficiently within a wide range of limits.

The changes in performance were substantial (see Figure 3). As measured from the initial baseline determination to the terminal session of the second training phase (speeds that could be maintained with an error rate of 20% or less), the average improvement was 65% among the younger men (range = 29% to 112%) and 66% among the older (range = 36% to 92%). An associated finding was that rapid responding continued when the temporal contingencies were removed. From the pretraining to the posttraining baseline, the average improvement was 43% among the younger men (range = 19% to 67%) and 48% among the older ones (range = 25% to 85%). A third aspect of the findings was that these changes involved both molar and molecular aspects of performance, that is, the man's average speed across a number of trials under a given contingency, as well as his speeds on the trials on which the averages were based (see Figure 4). Systematic reinforcement of responses occurring within a specified interval displaced the entire distribution of response speeds, and thus the characteristic reaction time of the individual.

An important feature of the above analyses is that estimates of maximum speeds were based on the fastest performances that could be maintained without a significant number of errors (fewer than 20%). The results indicated that subjects were capable of responding faster than this criterion but only at the expense of additional errors (see Figure 2). Blough (1978) described the relationship between speed and errors (the so-called "speed-accuracy trade-off") in terms of differing degrees of stimulus control. Slow accurate responding indicates good stimulus control of the choice response, whereas increasing errors as faster and faster responding is demanded indicates progressive loss of control. From the standpoint of the present procedures, the less severe time limits produced optimal choice reaction times, in that responding was simultaneously fast and under stimulus control. More severe time limits, while producing faster responding, converted the procedure from choice to simple reaction time, that is, to one in which responding was no longer under the control of the sample stimulus.

The major finding was that increased response speeds can be produced through training. In a recent review, Salthouse and Somberg (1982) commented that "a general assumption implicit in much of the literature on skilled performance is that simple tasks are immune to practice effects and are relatively pure assessments of capacity" (p. 177). However, these writers went on to argue that this assumption may be incorrect in the light of studies they cited reporting practice effects. In Salthouse and Somberg's own research, which involved training procedures lasting some 50 sessions (both younger and older adult subjects were studied), substantial improvements were observed on a number of tasks including reaction time, signal detection, and development of visual discriminations. The present results, then, which emphasize performances of individual subjects responding to an explicit set of operant contingencies, offer further evidence that response speeds can be altered through practice.

Unlike previous studies, the procedures provided separate determinations of the effects of practice (i.e., exposure to the task) and the effects of the reinforcers contingent on rapid responding (i.e., the messages plus the monetary gain that they signified). Response speeds increased during the initial baseline sessions when temporal contingencies were absent and usually stabilized after about six sessions. But speeds decreased further when the time limits were imposed and these improvements were maintained when the baseline conditions were reinstituted. This aspect of the results shows that continued exposure to the procedure, while leading to faster responding, was not the exclusive source of the improvements seen under the training and subsequent baseline conditions. Also critical was the procedure of reinforcing fast responding.

In general outline, the results resemble those originally obtained by Stebbins and Lanson (1961), when reinforcement contingencies were applied to the response speeds of infrahuman subjects. Another link to the animal literature concerns the present use of matching-to-sample and oddity-matching discriminations as the events controlling responding. Although there are reasons to suppose that the two discriminations should be equal in difficulty, experiments with animals trained with varied stimuli (as was the case in the present study) have indicated that oddity matching poses the more difficult problem (see Zentall & Hogan, 1978). The present study extends this result to humans. Also of interest is that the difference was apparent in speed of responding to the test stimuli, even when few or no errors were made (most animal studies have used errors as the performance measure).

Age Differences in Response Speed

The other question concerns whether age differences can be altered through training. The analysis indicated that training effects were approximately the same for the older and younger men so that the age differences seen initially were not diminished.

Kausler (1982) discussed both the hypothesis that behavioral deficits in older adults reflect disuse and the associated expectation "that practice on the task in question should bring proficiency back to where it was before the long layoff" (p. 119). In his review of the limited literature on this question, Kausler concluded that evidence in support of the disuse hypothesis has not been forthcoming. One of the most comprehensive studies, the aforementioned one by Salthouse and Somberg (1982), found substantial improvements in average performances of groups of younger and older subjects. But as was the case with the present findings (as well as other research involving speeded responding, e.g., Beres & Baron, 1981; Madden & Nebes, 1980), there was no clear indication that age differences were reduced. At least by default, then, these results provide support for the alternative conclusion that age differences reflect "a fundamental physiological change in the nervous system" (Salthouse & Somberg, 1982, p. 203). Perhaps it is well to add that physiological evidence of such changes in healthy older adults has not been reported.

This is not to say that there are no studies that found reduced age differences with extended practice. Murrell (1970) reported reduction, if not elimination, of age differences in choice reaction time after 12,000 trials conducted over several months; however, only one of three subjects was an older adult. Other research in our laboratory (Perone & Baron, 1982 and in press) also has shown improved performances by older adults to the extent that age differences were reduced. By comparison with the present procedures, the schedule was more complex (repeated acquisition of behavioral chains, cf. Boren & Devine, 1968), and there was more extended exposure to the temporal contingencies.

These limited findings do not allow definite identification of variables that may be critical for modifying deficits in response speed. A speculative hypothesis is that the likelihood of remediation is greatest when: (a) training is sufficiently prolonged; (b) training involves explicit contingencies for rapid responding; and (c) training involves complex patterns of responding. By the third, and perhaps the first of these criteria, the present research may have fallen short.

A suggestive line of evidence concerning procedures that might reduce age differences comes from research in the area of exercise physiology on physical fitness and response speed (see Spirduso, 1980, for a review). For example, one study (Spirduso, 1975) compared performances of sedentary older (50 to 70 yr) and younger (20 to 30 yr) men to those of men who regularly engaged in athletic pursuits requiring quick movements (squash, racketball, or handball). On standard reaction-time tests, the sedentary older men were on the order of 20% to 25% slower than their younger counterparts. By comparison, the difference was only 8% in the case of the athletically inclined older and younger men. As Spirduso noted, relationships of this sort are difficult to interpret and may be attributed to any one of a number of variables that distinguish active and sedentary individuals (e.g., cardiovascular fitness, smoking habits, motivation, etc.). However, a hypothesis consistent with our speculations is that the retardation of age-related declines seen in Spirduso's study reflected the contingencies to which the active older men regularly exposed themselves. Their athletic pursuits brought them into contact with a variety of complex natural contingencies that place close time limits on responding. Especially important is that, by comparison with the procedures that may be brought to bear in laboratory experiments, training in athletic settings is considerably more prolonged and intense (Spirduso's older men reported that they had engaged in the sports at least three times per week during the preceding 30 yrs).

Finally, it is important to emphasize that cross-sectional age comparisons of the sort made in the present study complicate the analysis by confounding cultural-generational differences with influences of age per se. We took pains to select older subjects who were comparable, insofar as possible, with the young-adult comparison subjects. The older men were active, healthy, and enrolled in a university program. Further, the extended nature of the procedures might be expected to sensitize them to the contingencies of the experiment and reduce the influences of their different histories. But various differences between the younger and older men still may be adduced—for example, that the reinforcers were less effective for the older men, that subtle sensory-perceptual deficits reduced their sensitivity to the discriminative stimuli, or that undiagnosed health problems interfered with their performances. Interpretations of the results must be qualified in terms of these and similar considerations.

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