*GLOBAL INCREASE IN RESPONSE LATENCIES BY
EARLY MIDDLE AGE: COMPLEXITY EFFECTS
IN INDIVIDUAL PERFORMANCES*

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Ten young women (age 20 to 22 years) and 10 middle-aged women (age 36 to 44 years) served as subjects in choice reaction time, letter classification, and abstract matching-to-sample tasks. In each of seven conditions, the older group responded more slowly than the younger group. Age differences showed a complexity effect. That is, differences between the latencies of young and old subjects increased as the latency of the young subjects increased. Both linear and power functions accurately described the relation between the latencies of the middle-aged and young adult groups. This was true not only for the relation between average latencies but also for the relation between corresponding quartiles of latency distributions. Similar results were observed at the individual level: All middle-aged subjects showed complexity effects, and, for each middle-aged subject, the relation between her latencies and those of the average young adult was well described by linear and power functions. These findings indicate that age-related slowing is apparent by age 40, and that complexity effects are observable in individual performances. This slowing is global and not specific to particular tasks, as indicated by the fact that the latencies of older adults can be predicted directly from those of younger adults without regard to the nature of the task.

Key words: age-related slowing, complexity effect, latency, button press, middle-aged and young women

Perhaps the most robust age-related change in adult behavior is the increase in response latencies associated with advancing age. Age-related differences are observed in the speed of performance on most everyday and laboratory tasks, and these differences are not eliminated when younger and older subjects are equated for intelligence, education, or health status (see Birren, Woods, & Williams, 1980, and Salthouse, 1985, for recent reviews). Moreover, although extensive training with procedures that reinforce speeded responding can reduce age differences, it does not eliminate them (e.g., Baron & Menich, 1985a, 1985b; Baron, Menich, & Perone, 1983).

Despite extensive research, most of which

has been based on an information-processing approach, a comprehensive explanation of age-related slowing remains to be developed. The dominant research strategy has been to attempt to isolate particular tasks that are sensitive to the effects of aging. Although older adults are slower than younger adults on virtually all tasks, the difference is much larger on some tasks than on others. Such differential slowing led researchers to hypothesize that tasks associated with large performance differences involve cognitive processes relatively sensitive to aging, whereas tasks associated with small performance differences involve processes that are relatively insensitive to aging (e.g., Bowles & Poon, 1985). However, a distinction between age-sensitive and -insensitive processes may be irrelevant, as indicated by recent reports that the latencies of older adults can be predicted from the latencies of younger adults without regard to the nature of the task (Cerella, Poon, & Williams, 1980; Hale, Myerson, & Wagstaff, 1987; Smith, Poon, Hale, & Myerson, 1988).

In their meta-analysis, Cerella et al. (1980) examined the results of published studies that employed a wide variety of tasks. Cerella et al. reported that the mean latency of an older adult group on any task could be predicted

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accurately from the mean latency of a young adult group on the same task by the equation $O = 1.36Y - 0.07$, where O and Y represent the latencies of the older and younger groups. Importantly, distinguishing between six different types of tasks and calculating six different regression equations did not appreciably increase the accuracy of predictions.

Hale et al. (1987) improved on previous efforts by establishing more objective criteria as suggested by Cerella et al. (1980). To minimize the role of age-related motor changes (see Welford, 1977, for a review), they selected for analysis only recent experiments in which the response was either pushing or releasing a button or key. In addition, the ages of the groups were held within as narrow bands as possible while still providing a sufficient yield of experiments for analysis. Hale et al. reported that the relation between the latencies of older (65 to 75 years) and younger (20 to 25 years) subjects in this carefully selected data set was not linear but was more accurately described by the power function, $O = 1.62Y^{1.29}$.

Hale et al.'s (1987) findings strongly reinforce the major implication of the Cerella et al. (1980) meta-analysis, that is, task-specific information is not required in order to predict latencies of older subjects from latencies of younger subjects because the speed of behavior in virtually all situations is affected by aging. Rather than varying with the specific nature of the task, the size of the age difference shows what is termed a *complexity effect* (Cerella et al., 1980). That is, the difference increases with the difficulty of the task as indexed by the latency of a young adult group. The Hale et al. findings add the important piece of information that the relation between the latencies of older and younger adults is nonlinear and is well described by a positively accelerated power function. Moreover, Hale et al. also demonstrated that the value of the exponent increases with the age of the older group.

Most research on age-related slowing has focused on the average performances of elderly and young adult groups. Recently, however, Smith et al. (1988) extended the findings of Cerella et al. (1980) and Hale et al. (1987) to the rest of the latency distribution. Smith et al. demonstrated that not only can the average latencies of an older adult group be predicted from those of a younger group performing the same task, but also that the best and worst

performances of the older group can be predicted from the corresponding performances of the younger group using the same equation.

The present study focuses on two questions. The first question is, "Is the complexity effect seen in performances of the elderly detectable in performances of middle-aged adults?" This question was addressed by examining the relation between the performances of a young adult group and a group in their early middle age. The second question is, "Can individual performances of older adults be predicted from the performances of a younger group?" Even when strong relations exist between group performances, these relations may not be observed in individual performances (e.g., Brown & Kirsner, 1980). To the extent that individual performances diverge from group averages, the theoretical significance as well as the diagnostic or clinical utility of such relations is limited. Therefore, this second question was addressed by examining the performances of individual adults of early middle age.

METHOD

Subjects

Two groups of women (10 young adults, ranging in age from 20 to 22 years, $M = 20.8$ years, and 10 adults in early middle age, ranging from 36 to 44 years, $M = 40.6$ years) served. Subjects in the young adult group were all undergraduate college students, and subjects in the middle-aged group were all undergraduates or college graduates.

Apparatus

Visual stimuli were presented on a Zenith® video monitor (Model ZVM-121) controlled by an Apple® II+ computer equipped with Cognitive Testing Station® (CTS) hardware and a Digitry®, Inc., response panel interface. Pascal programs were conjoined with CTS software to control the computer display and record response latencies. Latencies were timed using the CTS clock from the onset of each stimulus display (which always coincided with the initiation of a screen refresh cycle) to a button press that closed a microswitch. The CTS hardware and software permitted latencies to be measured with 0.01-ms accuracy.

Subjects responded on either of three push-buttons, each 2 cm in diameter, mounted on a response panel (15 by 15 cm). The left and

right response buttons were separated by 10.5 cm, center to center. A third button, which was used by the subject to initiate each trial, was located 8.0 cm below and midway between the left and right buttons.

Procedure

A battery of three speeded decision tasks was used. The first was a standard choice reaction-time task. The second was a letter-classification task designed by Posner and Mitchell (1967). The third was an abstract matching-to-sample task based on one designed by Hoyer, Rebok, and Sved (1979). Sessions lasted less than 45 min.

Subjects were given both general instructions and specific task instructions. They were informed that before each trial of each task an asterisk would appear in the center of the screen as a fixation point. When they were ready for the next trial, they were to press the lower button, denoted the READY button. Pressing the READY button resulted in presentation of the next trial 300 ms later. Subjects were instructed to respond to the stimuli presented on the screen by pressing the left or right button as quickly as possible while making accurate decisions. Prior to each task, appropriate labels were placed on the response panel directly above the left and right buttons, and instructions specific to the task were outlined (see description below). For all three tasks, a number of practice trials were presented before the experimental trials commenced. Within each task, the different types of experimental trials were interleaved according to pseudo-random sequences. No feedback as to the correctness of responses was provided on experimental trials.

Choice Reaction-Time Task

The stimuli for the choice reaction-time task were an L and an R, both 2.5 cm high and 0.75 cm wide. The subject was told to press either the left or right button (labeled L and R) depending upon which stimulus appeared. After six practice trials, 20 experimental trials with 10 of each stimulus were presented.

Letter-Classification Task

The stimuli for the classification task consisted of five letters of the alphabet displayed in either upper case or lower case (A, a, D, d, E, e, R, r, H, h) presented two at a time. All

upper-case letters were 1.75 cm high; lower-case letters were either 1.75 (d and h) or 0.75 cm (a, e, and r) high. All letters were 0.75 cm wide, and the separation between letters was 2.0 cm. The subject was told to indicate whether or not the letters were the same (i.e., had the same name) by pressing the button labeled Y for "yes" or the button labeled N for "no." Labels were placed so that yes responses could be made with the preferred hand. Subjects were given eight practice trials. There were 80 experimental trials consisting of 20 pairs of letters that were physically the same (PS condition), 20 pairs of letters that were the same in name only (NS condition), 20 pairs of different letters in which the cases were the same (SD condition), and 20 pairs of different letters in which the cases were different (DD condition).

Abstract Matching-to-Sample Task

The stimuli for the abstract matching-to-sample task consisted of three arrays, each of which appeared within a 6.5-cm square. Two squares separated horizontally by 2.2 cm were located at the top of the screen and a third square was centered 0.7 cm below them. Three characteristics of the arrays were varied: shape (diamonds, squares, or hexagons), orientation (horizontal, vertical, or diagonal), and number (two, three, or four elements). Each shape was 1 cm high and 1 cm wide. The subject was told to indicate which of the top two arrays, the left or the right one, was more similar to the bottom array by pressing the left or right button (labeled L and R for this task).

For each stimulus there was one relevant characteristic that determined the best match to the bottom array and two irrelevant characteristics. Two types of problems were presented. In the easier type of problem, shown in the upper panel of Figure 1, one irrelevant characteristic was identical and one was varied for all three arrays. In the more difficult type of problem, shown in the lower panel of Figure 1, both irrelevant characteristics were varied for all three arrays. Because of the complexity of the task, subjects were first shown sample stimuli and asked to indicate the more similar array verbally and explain to the experimenter why they made this selection. If they made an incorrect choice, they were corrected and told why the other array was the better match. Six practice trials were presented followed by 36

Fig. 1. Sample abstract matching-to-sample problems. The upper panel displays a Level 1 problem, in which one irrelevant characteristic (in this case shape) is held constant across all three arrays. The correct match is the upper left array and the relevant characteristic is number. The lower panel displays a more difficult Level 2 problem in which both irrelevant characteristics (in this case shape and orientation) vary across all three arrays. The correct match is the upper right array and the relevant characteristic is again number.

experimental trials consisting of 18 of each problem type to maintain counterbalancing.

RESULTS

Table 1 gives the latencies and error rates on all three tasks for both the middle-aged group and the young adult group. Although

error rates for both groups were quite comparable (ANOVAs calculated for each task revealed no significant group differences, all F values < 1.0), the middle-aged group was slower than the young adult group in each of the experimental conditions (ANOVAs calculated for each task revealed significant group differences, all F values > 5.75 , and all p values $< .05$).

Because individual response-latency distributions tended to be skewed, the average latency for an age group was calculated as the mean of the median latencies for the individual group members. In addition, the means of the first and third quartiles were also calculated. The relation between the latencies of the two groups may be seen in Figure 2, in which the first, second, and third quartile latencies of the middle-aged group are plotted as a function of the corresponding quartiles of the young adult group in the same condition. If the latencies of the age groups were equal, the points would fall along the diagonal line. Instead, the points all fall above the line, indicating that the middle-aged group was always slower.

The relation between the performances of the two groups is well described by either the linear function

$$E = 1.44Y - 0.131 \quad (1)$$

or the power function

$$E = 1.28Y^{1.11} \quad (2)$$

where E and Y are the latencies (in seconds) of the early middle-aged and young adult groups, respectively. Both functions account for more than 99% of the variance in the middle-aged subjects' latencies. However, because power functions are more general (see Discussion), only the power function is shown in Figure 2.

Power-function parameters were estimated by means of linear regression on the logarithms of the latencies. However, the variance accounted for was calculated based on the untransformed latencies predicted by the power function in order to compare these fits with those of simple linear functions. For curve-fitting purposes, only data from two conditions, PS and NS, of the letter-classification task were included in the analyses to prevent this one task from unduly influencing the fits. These two conditions were selected because the difference between NS and PS latencies has been of considerable interest to cognitive psy-

Table 1

Latencies (means of individual medians) and error rates for middle-aged and young adults on all three tasks.

Group and measure	Choice reaction time	Letter classification				Abstract matching	
		PS	NS	SD	DD	Level 1	Level 2
Young adults							
Latency (s)	0.415	0.564	0.656	0.664	0.693	1.573	1.819
Errors (%)	1.0	1.0	5.1	2.0	2.0	6.1	6.6
Middle-aged adults							
Latency (s)	0.502	0.659	0.816	0.764	0.813	2.197	2.595
Errors (%)	0.0	1.0	4.5	1.5	2.5	2.2	6.1

chologists who believe that it represents the time required by the "name-retrieval" process (e.g., Kail, 1986; Posner & Mitchell, 1967).

Individual analyses were consistent with the results of the group analyses (Figures 3 and 4). For each individual middle-aged subject, all three quartile latencies from each condition except PD and ND were plotted as a function of the corresponding mean quartile latencies of the young adult group, and the parameters of the best fitting linear and power functions were determined. These individual data were described precisely by both function forms (Table 2). The percentage of variance accounted for ranged from 94.6% to 99.6% (the medians for the linear and power functions were both 97.5%). In only 18 cases of 210 (10 individuals $\times$ 7 conditions $\times$ 3 quartiles) was the performance of a middle-aged individual faster than the average latency of the young adult group, and nine of these cases involved 1 subject, E7.

For each middle-aged individual, the correlation was determined between the mean of the median latencies for the young adult group in all seven experimental conditions and the size of the difference between that individual's median performance and the performance of an average young person. The strength of these correlations measures the degree to which a complexity effect exists, that is, the extent to which the size of the age difference increases with task complexity. These correlations were always positive and generally quite high (median = .911) and statistically significant in 9 of 10 cases, indicating the presence of complexity effects in individual performances. In the one case in which the correlation was not statistically significant (E7), the size of the age difference was also very small across all tasks (see Figure 4). The performances of slower

individuals were always characterized by strong complexity effects.

DISCUSSION

At the group level, the present findings indicate that a significant complexity effect is apparent by age 40: Middle-aged adults are, on the average, slower than young adults, and the age difference increases with task difficulty as indexed by the latency of a young adult group. Moreover, the size of the age difference may be predicted accurately based on the assumption that the latencies of older adults are a simple mathematical function (either a linear or power function) of the latencies of younger adults.

These findings are consistent with two complementary views concerning age-related behavioral changes. Specifically, the results support the view that age-related behavioral slowing is global in nature (e.g., Birren et al., 1980; Hale et al., 1987; Welford, 1984) and not confined to a small set of tasks or cognitive processes. The tasks employed in the present study varied greatly in difficulty and, even more importantly, were very diverse. Nevertheless, a simple mathematical formula could predict the behavior of the older group based only on the performance of the younger group: No information about the specific nature of the task was required to make such a prediction. This implies that it is not the task that determines the size of the age difference in response speed. Rather, it is simply the amount of time required to perform a task that determines the size of the age difference.

This conclusion is strengthened by the finding that the same relation exists between the average performances (median or second quar-

Fig. 2. Latency (in seconds) of the middle-aged group as a function of the latency of the young adult group for all three tasks. Open squares represent performance at the 25th percentile (Q1), filled circles represent performance at the 50th percentile (Q2), and open triangles represent performance at the 75th percentile (Q3). For each quartile (Q1, Q2, and Q3), group latencies are the mean of the individual quartile latencies. The solid line represents the best fitting power function ($E = 1.28Y^{1.11}$, $r^2 = .996$).

tile latencies) of older and younger adults on tasks of varying difficulty as between their better (first quartile) and poorer (third quartile) performances. Thus, as Smith *et al.* (1988) suggested, poorer performances on one task are like average performances on another, harder task, and better performances are like average performances on another, easier task. What is important is not the nature of the task, but the time taken to perform the task.

In addition, the current results are consistent with the view that aging is a lifelong process rather than something that occurs only towards the end of the life span. Although previous research (reviewed by Welford, 1977) has documented that age-related differences in the speed of performing very simple tasks may appear before the age of 40, the present study demonstrates that differences in performance of more difficult tasks are also apparent by this age. Moreover, we believe that the present experiment is the first to study age-related differences on a battery of speeded tasks with middle-aged adults, and hence the first to be

Table 2

Best fitting equations for the quartile latencies of middle-aged individuals.

Subject (age)	Linear	r^2	Power	r^2
E1 (40)	$1.52Y - 0.279$	.961	$1.18Y^{1.17}$	.964
E2 (41)	$1.36Y - 0.128$	.993	$1.20Y^{1.16}$	.988
E3 (41)	$1.44Y - 0.152$	.992	$1.25Y^{1.15}$	.991
E4 (44)	$1.47Y - 0.231$	.979	$1.19Y^{1.15}$	.981
E5 (44)	$1.60Y - 0.271$	.978	$1.27Y^{1.18}$	.980
E6 (42)	$1.95Y - 0.049$	.961	$1.87Y^{1.06}$	.960
E7 (42)	$1.12Y - 0.031$	.953	$1.07Y^{1.04}$	.955
E8 (37)	$1.16Y + 0.042$	.946	$1.19Y^{1.01}$	.947
E9 (36)	$1.59Y - 0.283$	.994	$1.24Y^{1.21}$	.996
E10 (39)	$1.21Y + 0.071$	.972	$1.28Y^{1.00}$	.971

able to report that the slowing already apparent by age 40 is global in nature.

Not only was the middle-aged group slower than the young adult group, but all of the individuals in the middle-aged group were slower than the average young adult in the present study. (Even the fastest middle-aged adult, E7, was slower than the average young adult in the majority of experimental conditions.) Although there is some diversity among the middle-aged individuals, the slower responses observed at the group level are not due to a few slower individuals but are, instead, truly representative of individual performances.

The present findings also demonstrate that the relation between the latencies of older and younger adults can be precisely described at the individual level using functions of the same forms as those that describe group performances. Moreover, these functions describe not only the average performances of individuals but their better and poorer performances as well. Although linear functions described the relation between the performances of our middle-aged and young adult subjects nearly as accurately as power functions, the power-function form has considerably more generality. Power functions describe the relation between elderly and young adult performances more precisely and over a greater range of latencies than linear functions do, although linear approximations will suffice over a short range (Hale *et al.*, 1987). The adequacy of linear functions in the present instance is predicted by our previous work showing that the non-

Fig. 3. Quartile latencies (in seconds) of middle-aged individuals (Subjects E1-E6) as a function of the young adult group latency. Solid lines represent the best fitting power functions given in Table 2. Conventions are the same as in Figure 2.

Fig. 4. Quartile latencies (in seconds) of middle-aged individuals (Subjects E7–E10) as a function of the young adult group latency. Solid lines represent the best fitting power functions given in Table 2. Conventions are the same as in Figure 2.

linearity of the relation decreases with the age of the older group (Hale *et al.*).

The power-function form is preferred not only because of its greater generality but also because linear functions actually lead to incorrect predictions regarding age-related differences in response speed. Linear functions tend to have negative intercepts when used to describe the relation between the latencies of older and younger adults (see Salthouse, 1985, for examples). As a consequence, such functions predict that older adults will respond faster than younger adults when the young adult latency is very short. By setting both E and Y equal to some unknown value, X , and solving for X , one can determine precisely what that very short young adult latency is. The

linear function (Equation 1) that describes the present data, for example, predicts that middle-aged adults will respond faster than young adults on any task that results in a young adult latency of less than 296 ms. This is clearly not the case, as indicated by a review of the simple reaction-time literature (Welford, 1977).

The same technique can be used with the power function (Equation 2) that describes the present data in order to determine whether this equation also predicts incorrectly that middle-aged adults will have simple reaction times shorter than young adults. On the contrary, the power function predicts that middle-aged women will be slower than young adults so long as the young adult latency is greater than 106 ms. The latencies of young adults on sim-

ple reaction-time tasks are always greater than this value, and thus the power function predicts that middle-aged adults will be slower, although the age difference will be smaller than on the more complex tasks employed in the present investigation. This prediction is confirmed by the literature (Welford, 1977).

Furthermore, Baron (1985) has pointed out the danger that different measurement scales may lead to different conclusions regarding age-related slowing. Linear relations (with negative intercepts) between latencies (seconds per response) would imply nonlinear relations between speeds (responses per second). However, if a power function describes the relation between the latencies of older and younger adults, then this necessarily implies that a power function also describes the relation between their speeds, and the value of the exponent is invariant over the transformation.

The present study did not use specific reinforcement contingencies for fast or accurate responding, nor was any attempt made to provide extensive practice or training. One might wonder, therefore, whether the source of age differences is a decline in the capacity for rapid responses or a lack of recent reinforcement for speeded performance. One might also wonder about age-related differences in instructional control: Older adults might be less inclined to respond quickly on unfamiliar laboratory tasks simply because someone asked them to do so.

Such views would cause one to expect that age differences should be eliminated with practice, especially if faster responding were reinforced. These expectations are clearly counter to results such as those of Baron and co-workers, who have found repeatedly that practice failed to eliminate age differences in speed (Beres & Baron, 1981; Falduto & Baron, 1986) even when monetary rewards were offered for faster responding (Baron & Menich, 1985a, 1985b; Baron et al., 1983). Moreover, practice fails to alter the relation between the latencies of older and younger adults. Although the latencies of both groups decrease with practice, an equation fit based on the relation between their unpracticed latencies can be used to predict accurately the practiced performances of older adults from the practiced performances of younger adults (Myerson, Hale, Wagstaff, Poon, & Smith, in press).

The work of Baron and others (see Birren et al., 1980, and Salthouse, 1985, for recent

reviews) clearly establishes that there is a real decline in the capacity for rapid responding with age. The important question then becomes whether this is specific to certain types of tasks or cognitive processes, or whether this decline is global in nature. The present results demonstrate that the longer latencies of middle-aged individuals may be predicted from the latencies of young adults without regard for the specific nature of the task, thus strongly supporting the hypothesis of a global developmental change.

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