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Isolating the Age Deficit in Speeded Performance[1]

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The 'locus' of the age-associated behavioral slowing was investigated with Sternberg's additive-factor method of identifying information processing stages. The factor of adult age was found to interact with manipulations assumed to influence stages concerned with stimulus encoding, internal comparison, and response preparation or execution. Since age appeared to affect each stage of information processing, it was suggested that the age-associated slowing phenomenon is general rather than specific.

Key Words: Information-processing stages, Reaction time, Speed, General slowing

ONE of the most pronounced of the behavioral changes associated with increased age is a slowing of nearly all speeded activities. While there has been a great deal of research investigating this slowing phenomenon, there is still little consensus as to the exact nature of the age-related speed reduction. Two broad alternatives for characterizing the nature of the slowing are: (a) it is universal in that all processes are affected to nearly the same extent; and (b) it is specific and limited to one or two discrete processes. The research to be reported in the current paper addresses the issue of the nature of the age-associated slowing with the goal of attempting to identify which of these two alternatives is better supported by the data.

One approach to specifying the nature of the age-associated slowing involves utilizing information processing techniques in an attempt to localize the age effect to a particular information processing stage. Several attempts of this type have been reported, but few have employed the same manipulations and thus the various studies have led to different conclusions about the localization of the age effect. For example, several researchers have utilized Sternberg's (1969a) memory scanning procedure and have reported that age differences exist in both the slope and the intercept parameters derived from this task (e.g., Anders & Fozard, 1973; Anders et al., 1972; Eriksen et al., 1973). The conclusion from these studies is that at least two different stages contribute to the age-related slowing, one concerned with the rate of scanning items in memory and the other concerned either with the processes of encoding or the processes of response preparation and execution. Two studies by Simon (1968; Simon & Pouraghabagher, 1978) reported that older adults were affected more than young adults by manipulations of stimulus factors, thus implicating the stimulus encoding stage as a source of difficulty for older adults. Other studies (e.g., Griew, 1959, 1964; Simon, 1967) have demonstrated that older adults exhibit greater increases in reaction time as stimulus-response compatibility is reduced, thereby suggesting that the stage concerned with response preparation and execution is particularly difficult in later adulthood.

Taken together, these studies seem to suggest that age differences might be evident in nearly all information processing stages. Before such a conclusion can be accepted, however, it is necessary to establish that age differences exist when the various manipulations are carried out with similar procedures in the same experimental setting. It is for this purpose that the present experiment was designed.

The additive-factor method of Sternberg (1969b) was used to identify the information processing stage or stages susceptible to the effects of adult age. The method is based on the simultaneous manipulation of two factors (e.g., adult age and presence or absence of a noise pattern on the stimulus) with inferences [illegible] pattern of statistical interactions. Sternberg has argued that factors that do not produce

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a statistical interaction can be assumed to influence different stages of information processing, while those that do interact with one another are likely to be influencing the same stage. Based on much systematic research manipulating combinations of experimental factors, Sternberg (1969b) has claimed that degradation of the stimulus primarily affects a stage of stimulus encoding, number of items in the memory set affects a comparison stage, and complexity or compatibility of the response affects a stage concerned with response preparation or execution. In the present experiment the variables just described were manipulated in addition to the age of the subject. If the age 'factor' interacts with any of the experimental factors we will conclude that the information processing stage associated with that experimental factor presents particular difficulty for older adults.

METHOD

Subjects. — Thirteen males and 11 females between the ages of 18 and 28 years, with a mean age of 20 years, and 12 males and 12 females between the ages of 64 and 81 years, with a mean of 71 years, participated in a single 1-hour session. None were residents of nursing homes or custodial institutions and all reported themselves to be in reasonably good health. The mean raw scores from the Wechsler Adult Intelligence Scale Vocabulary and Digit Symbol Substitution subtests were 62.1 and 76.9, respectively, for the young adults, and 72.7 and 44.4, respectively, for the older adults.

Apparatus. — A PDP-11 laboratory computer was used to present stimuli on a Hewlett-Packard Model 1311A Display Monitor, and to record responses and latencies to the nearest msec from a response panel containing two 10-key pushbutton telephone keyboards.

Procedure. — A trial in all conditions consisted of the 1.5 sec presentation of one or four randomly selected digits from the set 1 to 9, followed after 1.5 sec by a single target digit. The participants were instructed to press a key on the right keyboard if the target digit had been presented in the earlier list, and to press a key on the left keyboard if the target was not one of those in the earlier list. The probability of a four-item and a one-item comparison set and the probability that a target was in the earlier list was .5.

Four different conditions were created by orthogonally varying the complexity of the required response and the presence or absence of a degradation pattern on the target stimulus. The degradation pattern consisted of 20 randomly selected dots superimposed in the region of the target digit, which was also constructed with an average of 20 dots. Locations of the degradation dots were determined randomly on each presentation. The response manipulation involved instructing participants to press the "0" key on the bottom of each keyboard for the simple response but to press the key indicated by the target digit for the complex response. For example, if the comparison set was "3-6-8-4" and the target digit was "7", the appropriate response in the complex condition would be depression of the "7" key on the left keyboard ("7" because that was the target digit and left because the target digit was not in the earlier comparison set).

The order of the four conditions was counterbalanced across participants with each individual in each age group receiving a unique order of conditions. The conditions were also counterbalanced within individuals by presenting the four conditions for one trial block each in one order and then reversing the order for another four trial blocks. Each trial block consisted of 60 trials, with the first 10 considered practice and not included in the analyses. Setsize was manipulated within trial blocks as approximately one-half of the trials had a one-item setsize and approximately one-half had a four-item setsize.

RESULTS

It is often found in reaction time research that a few abnormally long reaction times tend to distort the distribution and make the mean value unrealistically high. Two procedures were employed to compensate for this possible skewness of reaction times in the present experiment. One involved computing the median rather than the mean of the reaction time distribution for each condition for each individual. This measure is not appropriate for interpretations with the additive-factor method (cf. Sternberg, 1969b), however, and another measure was computed by determining the mean of all observations except those greater than two standard deviations from the mean. Fortunately the pattern of statistical results was identical in all major respects with analyses of median and 'truncated mean' measures and therefore only the results with the truncated mean measures will be reported. An additional analysis based on the mean of correct trials only also yielded the same pattern of main effects and age interactions and thus the reported results with both correct and incorrect trials are not due to an artifact associated with incorrect responses.

The principal data consisted of the 'truncated mean' reaction time and percentage of error responses for the approximately 50 trials that each participant received with each of the eight combinations of degradation, response type, and size of comparison set. An analysis of variance conducted on the reaction times revealed that in addition to the main effects of age, $F\,(1,46) = 53.63$, $p < .0001$, $\omega^2 = .266$, and all experimental factors (i.e., all $F > 165.0$, $\omega^2 > .031$), the age factor interacted significantly with each of the other three factors: degradation, $F\,(1,46) = 17.52$, $p < .0001$, $\omega^2 = .004$, response type, $F\,(1,46) = 75.04$, $p < .0001$, $\omega^2 = .043$, and comparison set size, $F\,(1,46) = 11.60$, $p < .002$, $\omega^2 = .002$. Older adults were slower overall than younger adults, and the absolute difference between the groups increased with each manipulation. Figure 1 illustrates this pattern for each of the three experimental manipulations.

Other statistically significant ($p < .01$ because of the large number of statistical effects being evaluated) interactions were degradation × response type, $F\,(1,46) = 9.09$, $p < .0042$, $\omega^2 = .0009$, and degradation × comparison set size $F\,(1,46) = 7.39$, $p < .0092$, $\omega^2 = .0002$. Significant effects with the percentage error variable were: age, $F\,(1,46) = 19.67$, $p < .0001$, $\omega^2 = .054$, all experimental factors (i.e., all $F > 12.90$, $\omega^2 > .019$); age × degradation, $F\,(1,46) = 42.49$, $p < .0001$, $\omega^2 = .037$, age × response type, $F\,(1,46) = 15.24$, $p < .0003$, $\omega^2 = .022$, degradation × response type, $F\,(1,46) = 20.45$, $p < .0001$, $\omega^2 = .020$, and degradation × comparison set size, $F\,(1,46) = 15.51$, $p < .0003$, $\omega^2 = .009$. In all cases where

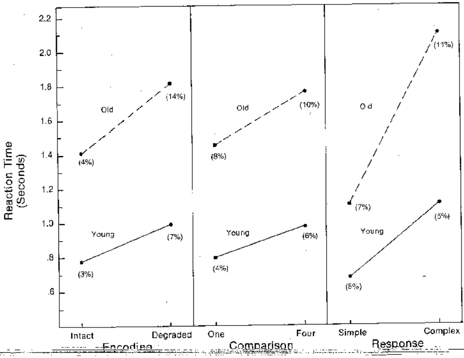

Fig. 1. Interactions of age with manipulations presumed to influence separate stages of processing. The numbers in parentheses represent the percentage of incorrect responses in that condition.

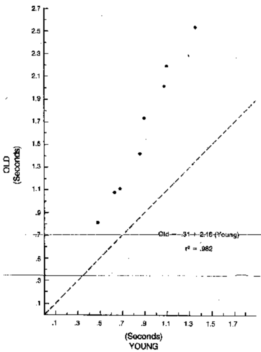

Fig. 2. Performance of old adults as a function of performance of young adults in the reaction time task of the current experiment. The dotted line represents a slope of 1.0 with an intercept of 0, and the equation indicates the parameters of the best least-squares fit to the data points.

both the time and error variables were significant the trend was in the same direction (i.e., errors increased as time increased).

The data were also examined by plotting the speed of the old adults in a given condition against the speed of the young adults in that same condition. Data presented in this fashion are illustrated in Fig. 2. Notice that the fit to a linear equation is quite good, and that the slope is considerably greater than 1.0 while the intercept is very close to 0.

Discussion

A major result of the current study is the finding that age interacts with each manipulation designed to affect a separate stage. The conclusion from this result is that age has an effect in each of the three stages investigated in this study. An input stage is implicated with the discovery that older adults are more affected than younger adults by adding a degradation pattern to the target stimulus; a comparison stage is implicated by the result that older adults have a greater increase in reaction time than younger adults when the comparison set has four items rather than one; and finally, an output stage is implicated in the finding that both time and errors are increased more in older adults than in younger adults by changing from a simple response to a complex response.

The finding that degradation interacted significantly with comparison set size and response type with both the reaction time and error variables suggests, according to additive factors logic, that the three variables did not each influence a separate stage. Instead, it appears that degradation may have had a primary effect on the encoding stage and secondary effects on the comparison and response stages. Several other studies have reported a similar finding (e.g., Meyer et al., 1975; Miller, 1979; Salthouse, 1981), and thus, while this complicates matters, it is not inconsistent with previous research. The complication arises because if the degradation manipulation influences more than one stage, then one can not be certain that the interaction of age and degradation is due to an age difficulty in the encoding stage. The availability of other evidence, such as consistent reports of age difficulties in tachistoscopic perception tasks (e.g., Hertzog et al., 1976; Till, 1978; Walsh, 1976; Walsh et al., 1978; Walsh et al., 1979) and the reaction time studies cited earlier (e.g., Simon, 1968; Simon & Pouraghabagher, 1978), however, indicates that there probably is a real age difficulty in the stage of stimulus encoding.

Although one might wish to determine the relative importance of the various stages for producing the age differences in speeded performance, quantitative assessments of the contribution of each stage are difficult to obtain because the magnitude of the age differences in a particular condition vary with the time required by the young adults in that condition. This point is illustrated by Fig. 2 where it is apparent that the absolute time differences between young and old adults increase monotonically with increases in the time needed for the young adults to perform the relevant activity. This empirical relationship indicates that the size of an age × manipulation interaction depends directly upon the magnitude of the manipulation's effect in the

performance of young adults. Therefore, unless the various manipulations produce effects of equivalent magnitude in the young adults, it is not possible to make meaningful inferences about the relative importance of different processes to the slower performance of older adults.

The empirical function of Fig. 2, along with similar functions reported in Brinley (1965) and Cerella et al. (1980), is consistent with an interpretation that suggests that nearly all cognitive processes are slowed by approximately the same proportional amount with increased age. By way of contrast, an interpretation that assumes that only a single stage concerned with input or output is affected by increased age would predict an additive (i.e., Time (Old) = Time (Young) + constant) relationship when data are presented in the form of Fig. 2. Many details remain to be elaborated concerning the implications of the multiplicative and additive formulations of the age-speed relationship, but these types of comparisons appear to have great potential for clarifying the precise nature of the age-related slowing phenomenon.

The finding that age differences are apparent in each of the three stages investigated, and the discovery of the multiplicative relationship between the speeds of young and old adults, both serve to support the hypothesis that the age difference in speeded performance is not easily localized in a specific information processing stage. Instead, it appears as though the slowing phenomenon may be general in nature and perhaps produced by a speed reduction in all central nervous system activity. This interpretation suggests that the degree of age-associated slowing depends upon the amount of central nervous system processing required in a given task and not upon the susceptibility of processes underlying each condition to the influence of age.

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