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Time-Accuracy Relationships in Young and Old Adults[1]

Timothy A. Salthouse, PhD, and Benjamin L. Somberg, PhD[2]

The relationships between reaction time and classification accuracy were compared in young (18 to 21 years) and old (60 to 84 years) adults in a choice reaction time task. Both young and older adults showed equivalent rates of increasing accuracy with greater time, but the temporal duration at which the accuracy first exceeded the chance level was shorter for young than for older adults. It was suggested that aging is associated with a slowing of the information integration and/or response preparation processes but not with a slowing of the actual rate of information extraction.

Key words: Speed-accuracy tradeoff, Processing capacity, Reaction time, Age-related slowing, Human

IN the same classic paper (1869/1969) in which he introduced his now famous stage model of reaction time, Donders also mentioned the problem of interpreting reaction time when individuals commit errors. For almost 100 years this problem of interpreting reaction time when accuracy is uncontrolled remained unsolved, and it has been only in the last decade that explicit procedures have been developed for the simultaneous analysis of both speed and accuracy aspects of performance.

The procedural innovation of recent years involves examining reaction time and error rate at several levels of speed and accuracy to determine the mathematical relationship between the two and, then, using this relationship as a measure of performance capacity. The empirical functions relating reaction time and accuracy have been termed speed-accuracy-operating characteristically by Pew (1969) and latency-operating characteristics by Lappin and Disch (1972) in recognition of their similarity to the receiver-operating characteristics of signal detection theory (e.g., Green & Swets, 1966). Like receiver-operating characteristics, different points on the function are assumed to reflect different decision criteria or response biases, and, thus, the function itself can serve as a strategy-independent measure of performance capacity. Both Pachella (1974) and Wickelgren (1977) have provided detailed discussions of the methodological advantages of using complete tradeoff functions in place of conventional reaction time measures.

In addition to the methodological importance of time-accuracy tradeoffs, Pew (1969) and Wickelgren (1977) have pointed out that more precise identification of the nature of an experimental factor's influence might be possible by examination of the parameters of the time-accuracy-operating characteristic. Recent empirical work (e.g., Salthouse, 1981) has indicated that the operating characteristic can be reasonably described by three general parameters: the intercept, slope, and accuracy asymptote. A schematic illustration of an idealized operating characteristic and the effects of varying each of the three parameters is presented in Figure 1. The shift in the point at which accuracy begins to increase with increased time, portrayed in Figure 1B, will be reflected in the intercept measure of a linear equation relating time to accuracy for the middle segment of the function. The change in the amount of increase in accuracy per unit time, depicted in Figure 1C, will be evident as a change in the slope measure of the linear equation. And finally, the change in the asymptotic high level of accuracy, represented in Figure 1D, can be summarized by the final measure of accuracy in whatever units are employed.

The effect of adult age on time-accuracy-operating characteristic parameters is particularly interesting since slower performance is often considered one of the primary behavioral characteristics of aging, and yet very little is presently known about the cause, or exact nature, of this reduction in speed. Moreover, previous research

[1] This research was supported by National Institutes on Aging Grant R01 AG 00694-01 to Dr. Salthouse.
[2] Department of Psychology, University of Missouri, Columbia, MO 65211.

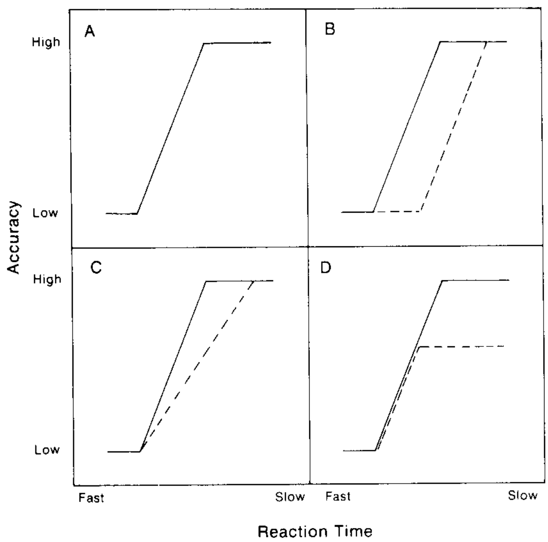

Figure 1. Schematic illustration of idealized time-accuracy-operating characteristic (A) and variations in intercept (B), slope (C), and accuracy asymptote (D).

comparing time-accuracy-operating characteristics in adults of different ages has been inconsistent with respect to the parameter most influenced by increased age. Rabbitt and Vyas (1970) did not report many details but suggested that older adults did not differ from young adults in the slope parameter but may have differed in the intercept parameter. Salthouse (1979) reported three experiments with time-accuracy-operating characteristics for young and older adults, but the results were not entirely consistent, and there was evidence of both intercept and slope differences in various comparisons. One problem with the Salthouse (1979) study was that the regression parameters were not computed from the individually determined best-fitting equations. Instead, all of the available data points were used for each participant, and since some individuals had data with either very low (chance) or very high (perfect) accuracy, this procedure resulted in relatively poor estimates of the true regression parameters for individual participants. The present experiment attempts to clarify the ambiguity currently surrounding the issue of which operating characteristic parameter is affected by increased age by comparing the individually determined slope and intercept parameters of young and old adults. Because the present discrimination task was quite easy, all participants achieved near perfect accuracy with long reaction times, and, thus, comparisons of the accuracy asymptote parameter per se are not meaningful. Of course, the time at which the asymptote is reached is an interesting and meaningful variable, but this can be derived from, and hence is not independent of, the intercept and slope parameters.

Definitive interpretations of the meaning of the various parameters are not yet possible, but certain speculations seem reasonable on the basis of the available evidence. For example, the slope seems to represent the rate of extracting information to discriminate between alternative representations because more discriminable stimuli lead to steeper slopes (e.g., Link & Tindall, 1971; Pachella & Fisher, 1969; Rabbitt & Vyas, 1970; Swensson, 1972). The intercept parameter apparently represents the duration of all processes except actual information extraction as it has been found to be greater with variations of such factors as (a) stimulus intensity (e.g., Lappin & Disch, 1972; Pachella & Fisher, 1969), (b) number of stimulus-response alternatives (e.g., Pachella & Fisher, 1972; Pew, 1969), and (c) distance of the stimulus from the fovea (e.g., Sterling & Salthouse, 1981). If these speculations as to the meaning of the intercept and slope parameters are accepted, the investigation of adult age effects should allow one to determine whether aging effects discrimination or information extraction processes less, more, or equally as much as other processes involved in speeded responses.

Method

Participants. — Forty college students (20 females and 20 males) between the ages of 18 and 24 years (M = 18.7) and 40 older adults (26 females and 14 males) between the ages of 60 and 84 years (M = 69.1) participated in a single experimental session. Preliminary analyses revealed no sex differences or age by sex interactions on the primary dependent variables and, thus, the sex variable was ignored in all subsequent analyses. Mean raw scores on the WAIS vocabulary subtest were 58.4 and 72.5 for the young and old adults, respectively, $t(78) = 7.27$, $p < .0001$. Mean raw scores on the WAIS digit symbol subtest were 65.9 for young adults and 46.8 for old adults, $t(78) = 7.33$, $p < .0001$. Most of the older adults were active or retired professionals, whereas all of the younger adults were college students. All participants reported themselves to be in reasonably good health.

Apparatus. — A PDP-11 laboratory computer controlled the presentation of stimuli on a Hewlett-Packard model 1311A display with a rapid decay P31 phosphor and recorded responses from a response panel containing two 10-key pushbutton telephone keyboards. Only the bottom-most (0) key on each keyboard was used. All temporal measurements were to the nearest millisecond.

Procedure. — A 1000-msec fixation stimulus, consisting of four dots in the corners of a square with 1° sides, was presented immediately before the target stimulus, which consisted of a 1.5° diagonal arrow oriented toward the lower left or lower right of the display. The direction of the target stimulus was indicated when the participant depressed the bottom-most key on the left (for the leftward pointing arrow) or the right (for the rightward pointing arrow) keyboard. After the response was registered a time line was displayed in which the desired time region for the response and the actual response time were indicated. The participants were instructed to attempt to respond within the designated time region regardless of the accuracy that might result. Two trial blocks were presented, separated by a short rest period. A trial block began with the desired time region between 375 and 475 msec, with the time region reduced in 50-msec steps until it reached 125 to 225 msec. That is, in the first 10 trials the participant was to respond between 375 and 475 msec, in the second 10 trials he or she was to respond between 325 and 425 msec, in the third 10 trials between 275 and 375 msec, and so forth. The time region remained at 125 to 225 msec until 10 responses were produced within the interval, at which point the time region increased to successively higher values with each additional 10 responses within the region, or until a total of 250 responses had been produced. If less than 10 responses fell within the designated time region, the time region continued at that level for all remaining trials. Informal inspection indicated no age differences in the number of responses required in the two age groups. This is a different procedure for generating time-accuracy functions than previously employed in aging investigations (Salthouse, 1979), but it has the advantages of being easier to understand and much more efficient in the collection of data.

Results

The responses for each participant, collapsed across the two trial blocks, were grouped in 50-msec intervals from 175 to 475 msec, and the percentage correct determined within each interval. Complete time-accuracy functions, computed by averaging accuracy across individuals at each time value, are illustrated in Figure 2.

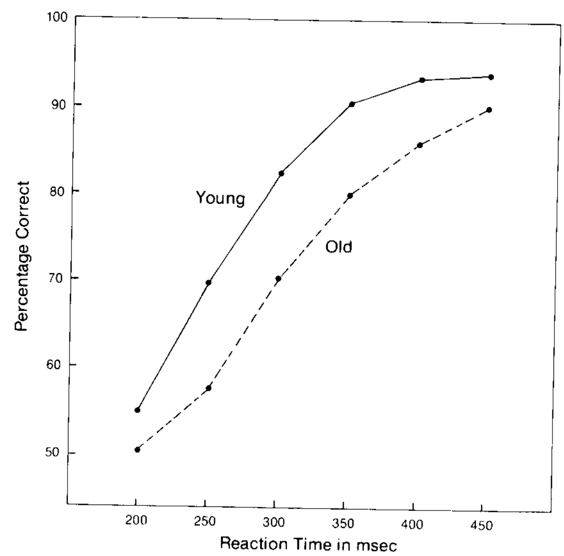

Figure 2. Time-accuracy-operating characteristic for young and old adults computed by averaging accuracy across individuals at each of six time intervals.

Least squares linear regression equations were fitted to each participant's data after omitting points at floor (50%) and ceiling (100%) levels to maximize the fit to a linear equation with at least three pairs of percentage correct and reaction time values. The correlations, indicating the goodness of fit to the linear equation, ranged from .834 to .999 with a median of .960 for the older adults and ranged from .845 to 1.000 with a median of .980 for the younger adults. The mean slopes, reflecting the amount of increase in accuracy per millisecond of time, were .270 for young adults and .261 for older adults, $t(78) = .46$, $p > .50$. Time intercepts, computed by using the regression parameters to predict the reaction time at 50% accuracy, averaged 176 msec for young adults and 222 msec for older adults, $t(78) = 4.70$, $p < .0001$.

Correlations were computed within each age group between age, vocabulary score, and digit symbol score and the two dependent variables, slope and intercept. The correlation between age and intercept in the older adults was significant ($r = -.335$, $p < .05$), but the direction was for increased age to be associated with faster intercepts. Since this is opposite to the overall age trend, it probably can be dismissed as a sampling fluctuation. No other correlations were significant in either the older adult or young adult samples. The lack of significant correlations between the intellectual measures and the dependent measures indicates that there is little relationship between these variables, and, thus, the differences between the age groups on the intellectual tasks can not be used to explain any performance differences between the young and old groups.

Discussion

The major result in this experiment is that young and old adults differ in the intercept but not the slope of the time-accuracy-operating characteristic. That is, although older adults require more time than young adults before their accuracy begins to improve above a chance level, the rate at which their accuracy increases is the same as young adults.

The discovery that there is not an age difference in a major component of speeded performance is rather unusual in that substantial age differences have been found in most speeded measures. In view of the moderately large number of individuals in each age group, and the discovery of a significant difference in the intercept parameter, we do not feel that the lack of a statistically significant difference in the slope parameter is due to a low-power test. Indeed, we have computed that in order for the .009 slope difference to reach the .05 level of significance with a power of .80, more than 600 individuals in each age group would have been required. Expressed somewhat differently, if the slope difference between age groups was 13%, one-half of the proportional age difference observed with the time intercept measure, the likelihood of detecting that difference in the current experiment was .95.

Other researchers have used the phrase "rate of information extraction" in a somewhat different manner than the current usage. The primary manipulation in the earlier studies has been the amount of information, defined in information theory terms as the log (base 2) of the number of stimulus-response alternatives. Results from these studies have been mixed; some investigators reported age differences in only the intercept parameter (e.g., Crossman & Szafran, 1956; Szafran, 1966), whereas others reported both intercept and slope differences (e.g., Suci et al., 1960). Welford (1977), in reviewing these and other similar studies, has offered speculations as to possible reasons for the discrepancies, but as he himself admits, at the current time they are merely speculations. There is not yet any consensus concerning the effects of adult age on the abstract "uncertainty reduction" measures of information extraction.

In the present context rate of information extraction simply refers to the amount of increase in classification accuracy per unit of time with the same set of two possible stimuli and two possible responses. Since very little information is available when responses are produced at chance (50%) accuracy but progressively more information is acquired as accuracy increases to the asymptotic level, it seems reasonable to interpret the slope parameter as a direct measure of rate of gain of information.

One way of conceptualizing this information extraction process is to imagine the sampling of discrete "pieces" (e.g., features, elements, segments) of stimulus information. Accuracy would be expected to increase in direct proportion to the number and value of the accumulated pieces of information. A change in either the number of pieces obtained per unit time, or in the "quality" (value or relevance) of the pieces, could lead to differences in the slope parameter. Based on the result (e.g., Link & Tindall, 1971; Pachella & Fisher, 1969; Rabbitt & Vyas, 1970; Swensson, 1972) that the slopes are steeper with more discriminable stimuli, which presumably contain more informative pieces relative to less discriminable stimuli, it might be concluded that the principal mechanism responsible for slope differences is the relevance or quality of the information pieces extracted at each sample. The surprising finding of the current study is that, regardless of the mechanism primarily responsible for producing slope differences, it apparently is not affected by increased age. Another possibility, considered very unlikely, is that age differences exist in opposite directions in the two mechanisms such that they exactly compensate for one another (e.g., fewer pieces per unit time but each piece of greater relevance).

It is not clear why the rate of information extraction or discrimination should be spared from the effects of increased age, whereas most other processes seem to become slower with age. One possibility is that the extraction process is automatic and independent of processing resources or capacity that may be declining with age. A problem in evaluating this hypothesis is that some researchers (e.g., Swensson, 1972; Thomas, 1974) have suggested that the slope of the time-accuracy function is itself a measure of processing capacity. If this interpretation is accepted, then the present results suggest that there is not an age difference in processing capacity, and, thus, the automatic effortful distinction is not meaningful in the present context. Until the concept of processing capacity is defined in a generally accepted fashion, therefore, it does not appear useful to incorporate it in "explanations" of other phenomena.

Further research is now needed to determine more precisely the nature of the operations contributing to the slope and time intercept parameters. Based on the proportional contribution to the overall reaction time, the slope parameter might be considered relatively unimportant. However, the markedly different age trends for the two parameters make additional investigation desirable, if for no other reason than to identify and more clearly understand processes relevant to speeded performance that are not affected by increased age. Among the variables that should be investigated with this technique are sample characteristics (the present older sample was highly educated and above average in verbal ability) and task complexity (the present arrow discrimination task is rather simple compared with other tasks that could have been employed). Until the present findings have been demonstrated to be generalizable to these other contexts they must be considered merely suggestive despite the unequivocal nature of the results with the present task and samples.

A secondary result in the present experiment is the replication of the Salthouse (1979) finding that adult age differences in reaction time cannot simply be attributed to age differences in accuracy emphasis. This conclusion is based on the finding that young and old adults differ in speed of performance even when comparisons are made at the same less-than-perfect levels of accuracy.

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