GLOBAL PROCESSING-TIME COEFFICIENTS CHARACTERIZE INDIVIDUAL AND GROUP DIFFERENCES IN COGNITIVE SPEED

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Abstract—Forty participants performed seven different information processing tasks (choice reaction time, letter classification, visual search, abstract matching, line-length discrimination, mental rotation, and mental paper-folding). Slow (top quartile) and fast (bottom quartile) processors were selected based on their mean z scores. Response times (RTs) of the slow and fast groups in the 21 conditions of the seven tasks were linear functions of the mean RTs of the entire group (both \( r^2 = .99 \)). In addition, individuals’ RTs were well described by linear functions (median \( r^2 = .93 \)). When tasks were ranked in order of complexity, the odd-even reliability of the ratio of an individual’s RT to the average RT was .80, indicating that such ratios remain relatively stable across tasks. Taken together, these findings indicate that the performance of an individual on diverse tasks can be predicted on the basis of a single processing-time coefficient. Such coefficients may provide useful indices of the efficiency with which different individuals process information.

Previous research on individual and group differences in mental ability suggests that a single factor underlies performance on information processing tasks, borrowed from the experimental laboratory, that tap fundamental cognitive operations (e.g., choice reaction time, short-term memory scanning, word classification, and sentence verification). When each individual subject is tested on the same battery of tasks, principal-components analyses frequently show only a single factor with an eigenvalue greater than 1, and this factor usually accounts for more than half of the variance in response time (RT) data (Miller & Vernon, 1992; Vernon, 1983; Vernon & Jensen, 1984). Although this finding is impressive, it is consistent with a variety of data structures and does not distinguish among them. For example, all individuals might be similarly affected by task manipulations so that increasing task complexity adds approximately the same amount of processing time to everyone’s RTs and individual ranks remain relatively stable across tasks. Or the effects of task manipulations might be to expand the differences among individuals, rather than maintaining constant differences, but without perturbing individual ranks. More complex relations between individuals’ RTs on different tasks will also result in a single speed factor so long as individuals ranks are relatively stable across tasks.

If, as Balota and Ferraro (1992) recently suggested, differences between groups and individuals of the same age are similar to age-related differences, then the structure of multitask RT data should be elegantly simple: The effects of task manipulations should be proportional to an individual’s information processing efficiency, and RTs of different individuals performing the same task should be multiplicatively related. This hypothesis is based on recent findings of a global developmental trend toward increased processing speed in children and a general slowing with age in adults: At any one age, all of the fundamental information processing components in children are slower than those of young adults by some constant proportion, and this proportion decreases as children get older (Hale, 1990; Hale, Fry, & Jessie, 1993; Kail, 1991; Kail & Park, 1992). Similar patterns are observed in cognitive aging. In older adults, processing of nonlexical information is more affected by age than is lexical processing, but general age-related slowing appears to have equivalent effects on all processing components within broad cognitive domains (e.g., Cerella, 1985, 1990; Hale, Myerson, & Wagstaff, 1987; Lima, Hale, & Myerson, 1991; Myerson & Hale, 1993; Myerson, Hale, Wagstaff, Poon, & Smith, 1990).

Thus, a particular age group can be characterized by a global processing-time coefficient, such that the RTs of the group on a variety of tasks may be predicted by simply multiplying this coefficient times the RTs of a young adult reference group (for recent meta-analytic reviews, see Cerella, 1990; Kail, 1991; Lima et al., 1991). If differences between individuals of the same age are similar to age-related differences, then individuals with different levels of ability and different ability groups also will show global differences in information processing speed. Thus, individuals and groups of the same age may also be characterized by global processing-time coefficients, such that their RTs on any task may be predicted by simply multiplying these coefficients times the average RT for that task. The results of studies concerned with the relation between processing speed and other mental abilities are consistent with such global speed differences. The evidence for a general speed factor that is correlated with both timed and untimed measures of intelligence (Vernon & Kantor, 1986; Vernon, 1991).

1. The relation between old and young adults’ RTs on nonlexical tasks is nonlinear, showing significant positive acceleration when examined over a sufficiently large range (Hale, Myerson, & Wagstaff, 1987; Myerson, Hale, Wagstaff, Poon, & Smith, 1990). Over a shorter range (RTs < 2 s), the relation is well approximated by a linear function. The relation between old and young adults’ RTs on lexical tasks is also linear over this range, although the slope is considerably smaller (Lima, Hale, & Myerson, 1991). It should be noted that the tasks used in the present study were all nonlexical, which may influence the generality of the findings.
Nador, & Kantor, 1985) suggests that processing speed may reflect the overall efficiency of the nervous system (Jensen, 1982; Vernon, 1987; see Jensen, 1993, for a recent review).

In order to address the question of whether global processing-time coefficients can predict the RTs of groups defined on the basis of characteristics other than age, we decided to group individuals on the basis of ability. That is, we sought to determine whether the relations between average RTs on various tasks and the RTs of groups of slow and fast individuals are independent of the task being performed. We began by analyzing data from 65 young adults who had previously participated in studies comparing children and young adults. Included in this analysis were RTs from 10 experimental conditions and four different information processing tasks (choice reaction time, letter classification, visual search, and abstract matching). We found that linear functions accurately described the relations between average RTs (i.e., mean RTs for the entire sample) and the RTs of the fast and slow groups, accounting for more than 99% of the variance in both cases.

However, the fact that a group's RTs on two quite different tasks are the same proportion longer or shorter than average provides less convincing evidence of task independence if these tasks differ in complexity than if they are of equivalent complexity, as indexed by equivalent average RTs. The use of tasks that overlap in terms of complexity has been recently promoted by Fisk, Fisher, and Rogers (1992). Moreover, neither the form nor the precision of relations involving aggregate measures such as group means necessarily reflects the form or precision of relations involving repeated measures of individuals (Estes, 1956; Sidman, 1952). For example, we found that the RTs of a slow group are the same proportion longer than average regardless of the task. This does not necessarily mean that the RTs of an individual member of that group are similarly well characterized by a global (task-independent) coefficient. The current experiment was designed to overcome possible limitations of our preliminary analysis by increasing the number of tasks in order to expand the range of complexity and in order to include tasks that involved quite different cognitive processes but were of comparable complexity. In addition, we analyzed not only the RTs of slow and fast groups but also those of each slow and fast individual in order to determine whether their RTs were always longer and shorter, respectively, by some constant proportion or global processing-time coefficient, regardless of the specific nature of the task.

METHOD

The participants were 40 undergraduate students at Washington University, St. Louis.

Stimuli were presented on a NEC MultiSynch 2A monitor controlled by a CompuAdd 286 computer. Stimulus presentation was synchronized with the refresh cycle for the monitor display, and response times were recorded with greater than 1-ms accuracy. The response panel housed three buttons arranged in an inverted triangle: Subjects used the left and right buttons to report decisions and the lower, center button to initiate trials.

Participants performed seven computerized tasks. In the choice reaction time task, participants decided whether or not two vertical arrows were pointing in the same direction, both up or both down (two conditions: same, different). In the letter classification task, participants decided whether or not two letters
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were the same (three conditions: name same–physically same, name same–physically different, and name different–physically different). In the visual search task, participants decided whether a red square target was present in an array of red circles and green squares (four conditions: set size 9–target present, set size 9–target absent, set size 25–target present, and set size 25–target absent). In the abstract matching task, participants decided which of two arrays of shapes that were presented to the left or right was the best match to a sample array. Each of the three arrays consisted of two to four circles, triangles, or squares that also varied in terms of color (red, blue, or green) and orientation (vertical, horizontal, or diagonal). The correct response was determined by selecting the array that shared the most dimensions in common with the sample (four conditions: four, three, two, or one dimension in common). In the line-length discrimination task, participants decided which of two lines was longer (two conditions: 10% difference, 20% difference). In the mental rotation task, they decided whether a letter (F, G, or R) was in the normal or mirror-reversed orientation (four conditions: rotation of 0°, 50°, 90°, or 130° from upright). In the mental paper-folding task, participants decided whether a piece of paper, folded and then hole-punched, that was pictured on the monitor would look like an unfolded piece of paper that was also pictured (two conditions: same, different). All conditions of all tasks consisted of 16 trials each, except for the name different–physically different condition of the letter classification task, which consisted of 32 trials so as to equate the number of same and different trials in this task.

Fig. 2. Individuals’ mean RTs as a function of group mean RTs. The RTs and best-fitting linear functions are shown for six individuals. The upper two panels are the data from the two fastest individuals (based on rank order of their mean z scores; see text for more details), the center two panels show the data from the two median individuals (i.e., ranked 20th and 21st), and the lower two panels show the data from the two slowest individuals. Conventions are the same as those used in Figure 1. Inter. = intercept.

GROUP RESULTS

Slow and fast groups were formed as follows: z scores were calculated for each of the 21 experimental conditions, and the mean of the 21 z scores was determined for each subject so that participants could be ranked based on their overall performance. The fast and slow groups consisted of the bottom and top quartiles (i.e., the participants with the 10 lowest and 10 highest mean z scores).
As may be seen in Figure 1, linear functions accurately describe the relations between average RTs in all 21 conditions and the corresponding RTs for the fast and slow groups, accounting for 99% of the variance in both cases. Although the intercepts differed significantly from zero ($t[19] = -2.03, p < .05$, and $t[19] = 3.56, p < .01$, for fast and slow RTs), the values of these intercepts were both very small: -41 and +65 ms for the slow and fast groups, respectively. Thus, when regressions were forced through the origin, a proportional relation between fast and average RTs still accounted for 98% of the variance, and a proportional relation between slow and average RTs accounted for 99% of the variance; the values of the global processing-time coefficients estimated with this procedure were 0.78 and 1.25 for the fast and slow groups, respectively.

**INDIVIDUAL RESULTS**

Precise relations between group mean RTs, such as those reported here, do not guarantee that similar relations will be observed at the individual level. Therefore, further analyses were conducted in order to determine whether individuals, like ability groups and age groups, could be characterized by global processing-time coefficients. Figure 2 shows the data from the two fastest, two slowest, and two median individuals plotted as a function of the average RTs. Performances of five of these individuals are well described by linear functions, and this pattern was typical of most subjects (median $r^2 = .93$; semi-interquartile range, $SIQ = .03$). Moreover, when a subject’s data were not well fit (as in the case of one individual in Fig. 2, U14), this usually appeared to be due as much to a lack of consistency within tasks as to a lack of consistency between tasks, suggesting measurement error rather than task-specific strengths and weaknesses.

The consistency of individuals’ processing speeds across tasks was further assessed by examining the ratio of each individual’s mean RT to the average RT for each task (for each individual on each task, RTs were averaged across all conditions, so that each task contributed only one value to the analysis). The standard deviation of the ratios was calculated for each individual, and the median standard deviation was low (.106; $SIQ = .047$). Odd-even reliability was determined by first rank-ordering the tasks based on complexity as indexed by the average RT, and then calculating the mean ratio for the odd tasks and the mean ratio for the even tasks for each individual. The odd-even reliability of the RT ratios was .80 for the entire sample of 40 subjects; when 2 outliers were excluded, odd-even reliability was .89.3

Additional evidence for a unitary speed factor is provided by a principal-components analysis of the RTs for the seven tasks. This analysis was conducted using each individual’s mean RT for each task, averaged across the various conditions, in order to weight all seven tasks equally and to maximize reliability. The results are given in Table 1. Intercorrelations were all statistically significant, and the squared multiple correlations among RT variables were consistently high. The lowest correlations tended to be between the easiest tasks and the most difficult tasks (where difficulty is indexed by the mean RT for each task), and this pattern is especially true for line-length discrimination and its correlations with the three most difficult tasks. The analysis revealed a single factor with an eigenvalue greater than 1.0 (value = 4.52). This single factor (processing speed) accounted for 64.6% of the variance, and the factor loadings for the RT variables were all very high, ranging from .720 to .892.

**GENERAL DISCUSSION**

Quantitative relations as orderly as any in psychology have been reported recently in the areas of cognitive development and cognitive aging: Simple mathematical functions permit the mean RTs of groups of children and older adults to be predicted from those of young adult groups without regard to the nature of the task, the predictions typically accounting for more than 90% of the variance (Cerella, 1990; Hale, 1990; Hale et al., 1993; Hale, Lima, & Myerson, 1991; Hale et al., 1987; Kail, 1991;...
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Kail & Park, 1992; Lima et al., 1991; Myerson et al., 1990; Salthouse & Somberg, 1982. The present experiment addressed two questions: (a) Do similar relations exist between the RTs of groups defined on the basis of characteristics other than age, more specifically, between average RTs and the RTs of groups of slow and fast processors? (b) Can the performance of individuals be accurately described by such linear relations? These questions were answered affirmatively in the present experiment by examining speed of performance on seven basic cognitive tasks that spanned a wide range of complexity and differed considerably in their componental makeup. A single regression line accurately described the relation between average RTs on all of the tasks and the RTs of the fast group, and another line accurately described the relation between average and slow performances.

Similar relations also accurately described the performances of individual participants. Like the relations between group RTs, linear functions fit to individuals' RTs from all 21 experimental conditions typically had very small intercepts and accounted for a very high proportion of the variance. In addition, ratios of individual RTs to average RTs were relatively stable across the seven tasks, as indicated by the high odd-even reliability of these ratios. These results at the level of the individual are consistent with the hypothesis that the global processing-time coefficient characterizes the speed of all of an individual's basic cognitive processes.

Whereas factor analyses suggest that a single factor underlies all speeded cognitive performance (Miller & Vernon, 1992; Vernon, 1983; Vernon & Jensen, 1984), the existence of a unitary unrotated speed factor such as that reported previously and replicated in the present study (i.e., one that is positively correlated with all RT variables and that loads approximately equally on all variables) means only that an individual's relative position in the population is relatively stable across tasks. The present results suggest not only that individual ranks are stable, but also that an individual's processing time coefficient, that is, the ratio of an individual's RTs to average RTs, is relatively constant across different tasks. Because different tasks may involve very different processing components, the implication is that all of an individual's cognitive processes are faster or slower than average to the same degree. Noncognitive contributions to RT measures, such as the time for neural messages to reach cortical sensory areas, or the time from when neural messages leave cortical motor areas until an overt response is recorded, may vary independently of cognitive speed, however, and could be responsible for the small intercept values observed when fast or slow RTs are regressed on average RTs (see Cerella, 1985, for a similar account of the relation between the RTs of elderly and young adult groups).

The present findings have obvious applications in the study of other kinds of individual differences, including differences in health status, both mental and physical, and differences in cognitive abilities other than processing speed. For example, preliminary evidence suggests that RTs of depressed subjects are proportionally longer than average on various tasks, implying that depression results in an increased global processing-time coefficient (Janer, Hale, Pardo, & Smith, 1992). Furthermore, age differences in individual performance on tests of mental ability may almost completely disappear when differences in speed are controlled for statistically (Hertzog, 1989; Salthouse, 1992; Schaie, 1989).

Modern cognitive psychology concerns how it is that people perceive present events, how they remember past events, and how they use information about both types of events to make decisions. The primary focus has been on determining what specific subprocesses make up the larger processes of perceiving, remembering, and deciding, and how these subprocesses are organized. The largely structural analyses involved in answering such questions provide a good basis for answering questions about individual and group differences in cases where people's thinking differs qualitatively, for example, where different strategies are used to solve the same problems. However, such structural analyses may provide less insight in cases where people's thinking differs primarily quantitatively.

The present findings demonstrate the utility of an alternative approach to individual and group differences in cognition, and provide new structural information as well. That is, the architecture of the human information processing system appears to be such that the speed of most basic cognitive operations covaries with individuals. Writing with respect to adult age differences in cognition, Cerella (1990) suggested that because the magnitude of age deficits in RTs depends on the amount, rather than the type, of information processing, we may be compelled to seek explanations at the neurobiological level rather than at the psychological level. The present findings suggest a similar conclusion with respect to ability-related differences in processing speed. The size of RT differences between groups as well as between individual and average group performances on seven quite different cognitive tasks was determined primarily by the amount, not the type, of processing required. This kind of task independence combined with the orderliness of the data may compel an account of individual differences in neurobiological terms. It would appear that only in such terms can one explain the remarkable parsimony of global processing-time coefficients.

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