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Task Complexity and the Speed and Efficiency of Elemental Information Processing: Another Look at the Nature of Intellectual Giftedness

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This study examined the speed and efficiency of elemental processing among the intellectually gifted. Groups of gifted and nongifted junior high school students were compared on several elementary cognitive tasks (ECTs) with no symbolic content and different degrees of requisite processing complexity. After controlling for the potentially confounding effect of knowledge base on the ECTs, results of this study further substantiated the significant relationship between elemental processing, task complexity, and intellectual giftedness. Differences between the gifted and nongifted groups on the ECT parameters increased monotonically with task complexity. Moreover, despite the fact that the ECTs used in this study have no information content and require no higher-order or metaprocesses for successful task completion, discriminant function analyses including the various elemental processing speed and efficiency measures correctly classified approximately 80% of all subjects. Implications of these results for theory relating giftedness to the speed and efficiency of elemental cognitive processes are discussed.

According to much contemporary research and theory in human information-processing, the main difference between intellectually gifted and normal individuals is the effectiveness of higher-order or metacognitive processes (e.g., Borkowski & Kurtz, 1986; Borkowski & Peck, 1986; Borkowski & Kurtz, 1986; Davidson, 1986; Davidson & Sternberg, 1984; Sternberg, 1986). A relatively minor role is attributed to differences in the lower-order cognitive processes (e.g., encoding, short-term memory scanning, and retrieval of information from long-term memory) that underlie all thought and action and are orchestrated by the metacognitive

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processes (e.g., Borkowski & Peck, 1986; Sternberg, 1986). Cohn, Carlson, and Jensen (1985) summarized the prevailing conception of intellectual giftedness as follows:

> It has been a common view that the relationship between speed of information processing in elementary cognitive tasks and general intelligence, as conventionally measured, is a threshold phenomenon—that above some rather average level of basic information processing capacity, variation in mental speed is no longer an important feature of intellectual prowess. According to this view, the essential difference between students who are considered as academically "average" and those who are considered as "gifted" is a difference in the amount of scholastic knowledge and specific high-level problem-solving skills and strategies that they possess. (pp. 621–622)

A considerable amount of recent evidence, however, suggests that elemental information-processing abilities may be more importantly related to intellectual giftedness than previously considered (e.g., Cohn *et al.*, 1985; Dark & Benbow, 1990, 1991, 1993; Jensen, 1989; Jensen, Cohn, & Cohn, 1989). Much of this research is closely related to a broader theoretical framework of human intelligence, the cornerstone of which is the postulate that individual differences in intelligence are determined in part by genetics and therefore influenced by biological functioning (e.g., Bouchard, Lykken, McGue, Segal, & Tellegen, 1990; Plomin, 1988). This approach is essentially reductionistic, aiming to ascertain the neurophysiological and psychological mechanisms that underlie individual differences in intelligence (see, e.g., Jensen, 1992; Vernon, 1993). Researchers in this area have begun by identifying significant correlates of intelligence that are closer to the interface between brain and behavior than traditional psychometric tests, such as averaged evoked potentials (e.g., Barrett & Eysenck, 1992; McGarry-Roberts, Stelmack, & Campbell, 1992), nerve conduction velocity (e.g., Vernon & Mori, 1992), speed of neural and synaptic transmission in the visual tract (e.g., Reed & Jensen, 1993), glucose metabolic rates in the brain as measured by the positron emission tomography (PET) scanning technique (e.g., Haier, Siegel, Crinella, & Buchsbaum, 1993), and the speed and efficiency of elementary cognitive processes (for reviews, see Vernon, 1987, 1990a). Many now believe that a clear and comprehensive picture of the nature of intelligence is emerging from the results of these investigations. As Vernon (1990b) summarized in a recent review of the literature, "put simply, persons who perform well on intelligence tests (who have high 'IQs') have brains that can operate faster and more efficiently than those of persons who perform less well" (p. 295).

THEORETICAL UNDERPINNINGS

The theoretical relationship between elemental information-processing speed and efficiency and intelligence is well articulated (e.g., Detterman, 1987; Eysenck, 1987; Jensen, 1992; Larson & Alderton, 1992; Larson & Saccuzzo, 1989; Lehrl & Fischer, 1990). This theory emphasizes the "hardware" components of intelligence, as opposed to the "software" components (such as strategies and metacognition), and is grounded in the basic principles of cognitive psychology. The most basic of these principles is the limited capacity of working memory (WM), the active aspect of short-term memory (STM). Limited capacity refers to the restriction of information from the perceptual system and long-term memory (LTM) that can be processed at any one time in WM. Besides limited capacity, information in WM either rapidly decays without continuous rehearsal or processing (e.g., Murdock, 1961; Peterson & Peterson, 1959), or is lost because of interference from new incoming information (see, e.g., Klatzky, 1975). To compensate for limited capacity, rapid decay, and interference, one must either continually process information in WM or store it in LTM. But the storage of information into LTM takes time and channel capacity, so there is a trade-off between the amount of information that can be simultaneously stored and processed (e.g., Baddeley & Hitch, 1974).

Given these well-established limitations of human information-processing, higher intelligence is hypothesized to be related to faster and more efficient elemental processing because more mental operations (such as encoding, rehearsing, inferring, mapping, transforming, retrieving, or storing) can be performed per unit of time before information decays in WM and without overloading the system. In addition, if WM capacity is a function of processing speed and the rate of information decay in WM (Lehrl & Fischer, 1988), then the faster the flow of information in the processing system, the greater the functional capacity of WM should be. The advantage of fast and efficient elemental processes also appears to increase on tasks involving complex information, controlled processing, or information loads that threaten the capacity of WM (Larson & Saccuzzo, 1989; Larson, Merritt, & Williams, 1988). Vernon (1993) explained the relationship between processing complexity and intelligence as follows:

> More complex [reaction time (RT)] tasks are expected to correlate more highly with intelligence, because, almost by definition, they impose increasing information-processing demands and thus more closely approximate the types of cognitive activity elicited by intelligence test items . . . As tasks move upward along a continuum of complexity, ranging from simple RT tests at one end, to more complex RT tests in the middle, to highly complex problem-solving tasks at the other end, speed-of-processing becomes increasingly important and is one determinant of a person's ability to perform the task(s) successfully (p. 181).

EMPIRICAL SUPPORT

The significant relationship between intelligence and elemental information-processing speed and efficiency has been substantiated in numerous independent studies (for reviews, see Vernon, 1987, 1990a) and supported by results of meta-analyses (Jensen, 1987; Kranzler & Jensen, 1989). Significant differences in elemental information-processing speed and efficiency have also been reported between groups of disparate levels of mental ability, such as that between normal, mentally handicapped (e.g., Baumeister & Kellas, 1968; Jensen, 1982), and gifted individuals (e.g., Cohn *et al.*, 1985; Goldberg, Schwartz, & Stewart, 1977; Hunt, Lunneborg, & Lewis, 1975; Keating & Bobbitt, 1978).

In an extensive investigation of the elemental information-processing abilities of intellectually gifted children, Cohn *et al.* (1985) administered Raven's Standard Progressive Matrices (SPM; Raven, 1966) and nine measures of elementary cognitive processes (called elementary cognitive tasks, or ECTs) to 130 gifted and nongifted junior high school students. The ECTs used by Cohn *et al.* measured the speed and efficiency of such elemental processes as STM scanning, retrieval of overlearned codes from LTM, and simple and choice RT, among others. They stated that "since these tasks contain virtually nothing in the way of intellectual or scholastic content, it is unlikely that complex problem-solving strategies are involved" (p. 622). Results of this study revealed that the gifted students performed significantly better than the nongifted group on all of the psychometric and chronometric tests. In addition, Cohn *et al.* found that the magnitude of the differences on the ECTs was monotonically (increasing) related to task complexity (as indexed by response latency) and almost as large as the difference between groups on the SPM. Measured in standard deviation units (σ), the mean difference between groups on the ECTs was 1.3σ, compared to a difference of 1.9σ on SPM. A discriminant function analysis including all of the ECT variables also correctly classified approximately 90% of the gifted and nongifted subjects. Cohn *et al.* concluded from these results that "more of the difference between the gifted and nongifted groups must be attributed to differences in elementary cognitive processes than to higher-level problem-solving strategies, planning, executive control, or the other types of metaprocesses" (p. 629). If these results are valid and replicable, further refinement of current information-processing theories of intellectual giftedness would appear to be necessary (see Dark & Benbow, 1993).

SHORTCOMINGS OF PREVIOUS RESEARCH

One possible criticism of many of these investigations of gifted individuals' elemental processing abilities, such as Cohn *et al.* (1985), concerns their reliance on ECTs involving the presentation of symbolic stimuli (viz., digits, letters, or words). According to Ceci (1990a, 1990b), the results of these ECTs are inherently confounded because the speed and efficiency of elemental processing will be affected by the elaborateness and structure of the knowledge base that must be accessed to successfully complete the task. Ceci (1990a) stated that "an identical biologically based cognitive process will be associated with different performance outcomes if it is deployed on knowledge bases of varying degrees of elaborateness and structure" (p. 71). The superior performance of the gifted group on the ECTs in Cohn *et al.* (1985), and other similar studies, therefore, could have resulted from a more elaborate knowledge base among the intellectually gifted, not from faster and more efficient elemental processes.

Those investigations of giftedness that used ECTs with non-symbolic stimuli unfortunately do not provide a definitive answer to this question, due to the fact that tasks with a limited range of requisite processing complexity were employed (e.g., Hermelin & O'Connor, 1980; Keating & Bobbitt, 1978; Lally & Nettelbeck, 1977; McCauley *et al.*, 1976). For example, in a frequently cited study, Keating and Bobbitt (1978) administered simple RT (one light) and choice RT (two lights) tasks to subjects of average and above-average intelligence. Results revealed significant main effects, with above-average subjects performing faster than average subjects, but the absence of a group × RT task interaction effect, thereby suggesting that the complexity of elemental processing is not integrally related to giftedness. As Brewer (1987) noted, however, the absence of a significant interaction effect could be related to the fact that the choice RT task used in this experiment was only slightly more complex than the simple RT task. Results of Jensen's (1987) recent meta-analysis of 31 independent studies of similar ECTs, with a total $N = 1{,}129$, support Brewer's conjecture. These results indicate that the difference in requisite processing complexity between the one- and two-choice RT tasks employed by Keating and Bobbitt (1978) did not afford a sufficient test of the relationship between intellectual giftedness and elemental processing complexity.

In sum, further investigation of the relationship between intellectual giftedness, elemental information-processing speed and efficiency, and task complexity is needed. The aim of this study is to conduct such an analysis by comparing intellectually gifted children with academically average children on several ECTs with no symbolic content and different levels of requisite processing complexity.

METHOD

Subjects

Gifted subjects in this study were 55 volunteers (18 females, 37 males) between 11 and 14 years of age (Mean = 13.0, $SD = .8$) from the Academic Talent Development Program (ATDP) at the University of California, Berkeley. The ATDP is a summer program that provides enriched learning opportunities for academically talented students. Admission to the program is largely based on scores from the Scholastic Aptitude Test (SAT). The mean SAT Verbal and Quantitative scores for the gifted subjects in this study were 448.5 (SD = 102.7) and 516.3 (SD = 119.8), respectively. The admission requirements for the ATDP compare favorably with The Study of Mathematically Precocious Youth, in which mathematically talented adolescents were defined as seventh graders with SAT-Quantitative scores above 500 (Dark & Benbow, 1990). The nongifted group in this study consisted of 53 students (28 females, 25 males) between 11 and 14 years of age (Mean = 11.9, SD = .8), selected randomly from the regular education classes of a middle school in North Central Florida.

Procedures

Subjects were first administered Raven's Advanced Progressive Matrices (APM; Raven, 1966) with the standard instructions and under nonspeeded conditions. They were then individually administered the ECTs. Total testing time was approximately 45 min. For each ECT, subjects were instructed to perform as fast as they could without making errors. They were also given as many practice trials as needed before beginning testing.

Elementary Cognitive Tasks (ECTs)

Subjects were administered the following three ECTs: Simple RT (SRT; one-choice), choice RT (CRT; eight-choice), and the relatively new Odd-man paradigm, which is essentially a measure of the speed and efficiency of spatial discrimination (see, e.g., Kranzler & Jensen, 1991).

The same apparatus and procedure were used for both SRT and CRT. The apparatus consists of a 13 in. × 17 in. console tilted at a 30° angle. The "home button," a black push button 1 in. in diameter, is located at the lower center of the panel. The response buttons are an array of eight green push buttons, ½ in. in diameter, which can be illuminated. They are arranged equidistantly from the home button in a semicircle with a 6 in. radius. Plastic flat black overlays can be fastened to the console exposing different push-button combinations. Only one push button was exposed for SRT. All eight push buttons were exposed for CRT.

The procedure for a single trial consists of: (1) subjects depress the home button; (2) an auditory warning signal (a "beep" of 1 s duration) is presented; (3) following a random interval of 1 to 4 s, one of the push buttons is illuminated; (4) subjects, as quickly as possible, remove their finger from the home button and depress the push button that has gone on. The apparatus allows the separate measurement of RT and movement time (MT). RT is the amount of time it takes subjects to lift their finger off the home button after one of the push buttons has been illuminated. MT is the interval between releasing the home button and depressing the push button. RT and MT are recorded in milliseconds by two electronic timers.

The procedure for the Odd-man is identical to that described for the SRT and CRT, except that instead of one push button going on, three push buttons are illuminated simultaneously, two of which are closer together than the third. The subject must depress the push button that is further away from the other two. RT and MT are recorded in milliseconds by two electronic timers.

Each subject was administered 20 SRT trials, 32 CRT trials, and 36 Odd-man trials.

RESULTS

As preliminary analyses revealed no significant effect of gender on the variables measured in this study, the data for males and females were collapsed within the gifted and nongifted groups in all analyses. Descriptive statistics for the chronometric and psychometric variables are shown in Table 1. The mean raw score of 27.1 for the gifted group on Raven's APM is slightly higher than the mean of a recent sample of 101 undergraduates at University of California, Berkeley (Kranzler & Jensen, 1991). The mean of 12.2 (SD = 5.8) for the nongifted group, in contrast, falls within the average range in comparison to peers of approximately the same age (Raven, Court, & Raven, 1983). The gifted–nongifted difference of 14.9 raw score points on the APM is significant ($t = 9.48$, $df = 106$, $p < .001$). In standard deviation units (σ), where σ is calculated as the square root of the average within-group variances, this difference equals 1.74σ, which corresponds to about 26 points on an "IQ" scale ($SD = 15$).

The descriptive statistics for the ECTs are also shown in Table 1. Four experimental variables were measured for each ECT. RT and MT were measured as the median of each subject's RT and MT trials; whereas the intraindividual variability of each ECT was measured as the *SD* of RT and MT over each subject's trials. The RT and MT medians and intraindivid-

TABLE 1
DESCRIPTIVE STATISTICS FOR THE CHRONOMETRIC (IN MSEC) AND PSYCHOMETRIC VARIABLES AND MEAN GROUP DIFFERENCES (IN σ UNITS)

	Gifted[a]		Nongifted[b]		
Variable	Mean	(*SD*)	Mean	(*SD*)	σ Diff.
Simple reaction time					
RT	311	(71)	320	(50)	.15
RTSD	49	(28)	56	(32)	.23
MT	169	(49)	223	(56)	1.03
MTSD	82	(53)	132	(90)	.68
Choice reaction time					
RT	361	(45)	402	(59)	.78
RTSD	51	(20)	73	(34)	.79
MT	188	(50)	277	(69)	1.48
MTSD	101	(46)	159	(83)	.87
Odd-man-out					
RT	513	(83)	641	(121)	1.24
RTSD	95	(26)	166	(71)	1.34
MT	216	(66)	344	(104)	1.48
MTSD	145	(41)	214	(79)	1.10
Raven's advanced matrices					
	27.1	(9.8)	12.2	(5.8)	1.74

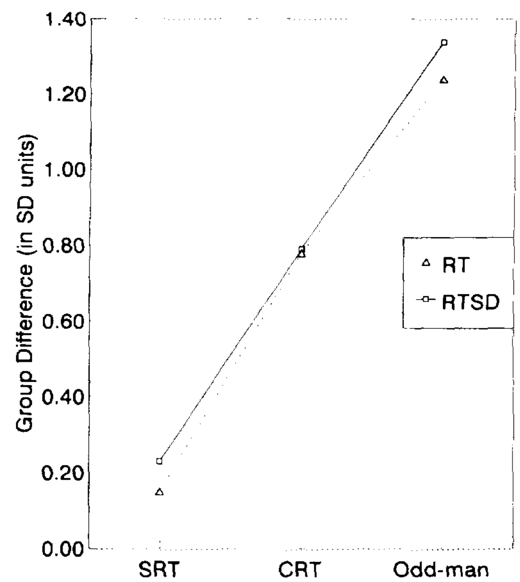
Note. RT, Median Reaction Time; MT, Median Movement Time; RTSD, intraindividual variability of RT; and MTSD, intraindividual variability of MT; σ Diff. = Difference between gifted–nongifted groups in standard deviation units (σ).

[a] $n = 55$.

[b] $N = 53$.

ual variabilities in this study are comparable to those obtained from similar samples of gifted and nongifted adolescents (e.g., Cohn *et al.*, 1985).

Also shown in this table are differences across the ECT variables in σ units. Using average response latency as an objective index of task complexity, with longer response latencies corresponding to more complex tasks, the difference between the gifted and nongifted groups on the RT medians and intraindividual variabilities increases monotonically with task complexity, as predicted by Cohn *et al.* (1985). The differences across the RT medians and intraindividual variabilities are also shown in Fig. 1. It is interesting to note that the size of the difference on the Odd-man is approximately three-fourths as large as the difference between groups on the APM, despite the fact that the Odd-man is entirely devoid of information content and requires no higher-order or metaprocesses for successful task completion. Differences between gifted and nongifted groups on MT have not previously been reported in the litera-



	SRT	CRT	Odd-man
RT	0.15	0.78	1.24
RTSD	0.23	0.79	1.34

Elementary Cognitive Tasks

FIG. 1. Differences between the Gifted and Nongifted Groups (in *SD* units) across Elementary Cognitive Tasks (simple reaction time, SRT; choice reaction time, CRT; Oddman paradigm, Oddman). Reaction time (RT) is measured as the median of each subject's RT trials, whereas the intraindividual variability of reaction time for each ECT was measured as the *SD* of RT over each subject's trials (RTSD).

ture. Interestingly, some of the largest differences between groups on the ECTs are on MT.

The significance of the differences on the ECTs was examined by conducting a set of one-way MANCOVAs across the items in each of the four blocks of ECTs (i.e., RT medians, RT intraindividual variabilities, MT medians, and MT intraindividual variabilities), with group (gifted vs nongifted) as the group factor and age as the covariate. Age was used as the covariate to control for the significant difference between groups in age ($t = 7.33$, $p < .01$). Post hoc univariate tests were conducted in the event of significant multivariate effects. The results of these analyses are shown in Table 1.

Results of the one-way MANCOVA for the RT medians revealed a significant main effect for group ($df = 3, 102$; $F = 6.47$; $p < .001$). Post hoc univariate analyses revealed significant main effects for group on the CRT and Odd-man tasks ($ps < .05$), but not for SRT, with the gifted group evincing faster RTs than the nongifted group. Results of the one-way MANCOVA for the RT intraindividual variabilities also showed a significant main effect for group ($df = 3, 102$; $F = 8.35$; $p < .001$). Post hoc analyses revealed significant main effects for group on CRT and the Odd-man ($ps < .05$), but not for SRT, with the gifted group showing less variability among RT trials than the nongifted group. For the MT medians, results of the one-way MANCOVA showed a significant main effect for group ($df = 3, 103$; $F = 10.93$; $p < .001$). Interestingly, and in contrast with the RT measures, post hoc univariate analyses revealed significant main effects on all three items ($ps < .05$), with the gifted group performing faster in each case. Lastly, results of the one-way MANCOVA for MT intraindividual variability also showed a significant main effect for group ($df = 3, 103$; $F = 7.90$; $p < .001$). Post hoc univariate analyses showed that the gifted group demonstrated significantly less inter-trial variability for all three ECTs ($ps < .05$).

Discriminant function analyses were conducted to determine the maximum discrimination between the gifted and nongifted group that could be attained with the various ECT measures. The classification rate in each analysis is significantly better than chance ($ps < .001$). The first of these analyses included the RT medians for each ECT. The resulting discriminant function correctly classified 73.8% of all subjects, 77.8% of the gifted group, and 69.8% of the non-gifted group. The second analysis included the RT intraindividual variabilities for each ECT. This discriminant function correctly classified 78.5% of all subjects, 92.6% of the gifted group, and 64.2% of the non-gifted group. The third discriminant function included the MT medians for each ECT. The resulting discriminant function correctly classified 80.5% of all the subjects, 81.8% of the gifted group, and 79.2% of the non-gifted group. The fourth and final analysis included the MT intraindividual variabilities for each task. This discriminant function correctly classified 74.1% of all subjects, 81.8% of the gifted group, and 66.0% of the non-gifted group. It is interesting to note that in each discriminant function analysis a larger percentage of the gifted group was correctly classified than the nongifted group. This finding is consistent with the results of Cohn *et al.* (1985) and may indicate the presence of unidentified gifted students in the nongifted group.

DISCUSSION

This study further investigated the relationship between intellectual giftedness and elemental information-processing on several ECTs with non-symbolic stimuli and different degrees of requisite information-processing complexity. After elimination of the potentially confounding effect of differences in knowledge base, the results of this study revealed that differences between gifted and nongifted individuals on the ECTs are systematically related to requisite processing complexity. These results thus indicate that intellectually gifted and normal individuals differ importantly not only in terms of the effectiveness of higher-order or metaprocesses, as maintained by current theories of giftedness (e.g., Borkowski & Kurtz, 1986; Borkowski & Peck, 1986; Davidson, 1986; Davidson & Sternberg, 1984; Sternberg, 1986), but also in terms of the speed and efficiency of lower-order cognitive processes. In fact, Cohn *et al.* (1985) conjectured that differences between gifted and normal individuals in general knowledge base and the effectiveness of higher-order cognitive processes are a function of elemental processing speed and efficiency over time. They hypothesize that:

> Seemingly small differences in speed of mental processing, when their effects are cumulated over the months and years of the individual's encounters with all the opportunities for information processing afforded by the environment, can result eventually in great differences in the amount of general knowledge and intellectual skills we see manifested in the contrasts between [gifted] and [nongifted] groups, not only in tests of scholastic aptitude, but in actual proficiency in intellectually-demanding tasks. (Cohn *et al.*, 1985, p. 628)

In addition to these findings, one unanticipated result of this study was that the gifted and nongifted groups differed as much on MT as on RT. This finding is particularly interesting because RT and MT are seen to reflect quite different aspects of information-processing. A recent meta-analysis of the results of numerous studies concluded that "MT displays little, if any, resemblance to RT" (Jensen, 1987, p. 122). Moreover, results of a recent hierarchical factor analysis of a large battery of ECTs and psychometric tests revealed that MT loads on a second-order factor that is orthogonal to psychometric *g*, on which RT has a substantial loading (Carroll, 1991). These results may therefore indicate that gifted and nongifted individuals differ significantly in the speed and efficiency of peripheral (or non-cognitive) components of ECT variance (see Jensen, 1986). The significant relationship that has recently been reported between nerve conduction velocity and intelligence may substantiate these results (e.g., Vernon & Mori, 1992). As this is the first study to report differences between gifted and nongifted individuals on MT, further research is obviously necessary.

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