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INDIVIDUAL AND GROUP DIFFERENCES IN INTELLIGENCE AND SPEED OF INFORMATION PROCESSING

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Summary—A battery of eight different reaction time (RT) tests, measuring the speed with which individuals perform various elementary cognitive processes, and a group test of scholastic aptitude (the Armed Services Vocational Aptitude Battery, ASVAB) were given to 50 black and 56 white male vocational college students. The regression of the general factor scores of the ASVAB on the RT measures yielded a shrunken multiple correlation of 0.465. Although discriminant analyses, when applied separately to the ASVAB subtests and to the RT variables, showed highly comparable overall discrimination (over 70% correct classification) between the black and white groups, factor scores derived from the general factor (labeled 'speed of information processing') of the RT battery show only about one-third as large a mean black–white difference as the mean group difference on the general factor scores derived from the ASVAB. Comparisons were also made between the 106 vocational college students and 100 university students of higher average academic aptitude who had previously been tested on the same RT battery (Vernon, 1983a). These groups showed marked differences on the RT variables, the largest differences occurring on the tests that required more complex cognitive processing. The more complex RT tests also correlate most highly with the psychometric measures of ability within each group. The results are consistent with the hypothesis that individual differences and the mean differences between groups in psychometric abilities and scholastic achievement are related to differences in the speed of information processing as measured in elementary cognitive tasks.

INTRODUCTION

In a recent article, Vernon (1983a) studied the relationship between a number of measures of speed of cognitive information processing and general intelligence among a sample of university students of above-average mental ability. The cognitive measures included simple and choice reaction time (RT), speed of encoding, speed of short-term memory (STM) processing, speed of retrieval of information from long-term memory (LTM) and the trade-off between the amount of information *S*s could store in STM while simultaneously processing other (unrelated) information. The measures of intelligence were the Wechsler Adult Intelligence Scale (WAIS) and the Raven Advanced Matrices (RAM). The primary parameters of interest on the cognitive tests were *S*s' RTs and intra-individual variability in RTs over repeated trials (intra-SDs).

The main findings of Vernon (1983a) are as follows.

1. RTs on the cognitive tests were highly intercorrelated and loaded on a single factor which accounted for 65.5% of the variance. This was initially interpreted as showing that *S*s' performance on these tests was largely determined by a single speed-of-processing factor. Intra-SDs were also highly correlated across tests and similarly loaded on a single factor.

2. Subsequent analyses, employing various combinations of RTs which tapped more specific cognitive processes, did not support the single-factor hypothesis. Rather, factor analysis with Varimax rotation produced three clearly defined factors

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representing STM storage–processing trade-off, LTM retrieval and STM processing (in order of variance accounted for).

3. Multiple regression analyses indicated a fairly pronounced relationship between the cognitive tests and the measures of intelligence. A shrunken multiple R of 0.464 was obtained when Full-scale WAIS IQ was regressed on RTs and intra-SDs. Corrected for the restriction of range in IQ of this sample, this correlation rose to 0.668. Separate analyses showed that RTs and intra-SDs each accounted for approximately the same amount of variance in WAIS IQ scores.

4. Another series of analyses indicated that the observed relationship between IQ scores and the cognitive tests could not be attributed to any content in common to the two types of tests nor, more importantly, to the fact that some subtests of the WAIS are timed.

The overall conclusion was that individual differences in IQ test performance reflect differences in the speed and efficiency with which persons can execute a number of elementary cognitive processes.

A number of well-known concepts in cognitive psychology suggest the possible mechanisms that might account for the relationship between measures of speed of information processing and performance on tests of intelligence, as elaborated elsewhere (Jensen, 1982; Vernon, 1983b). Briefly, it is assumed that although different kinds of intelligence tests may differ radically in appearance and surface content (e.g. vocabulary, block design, arithmetic, matrices), persons must carry out a number of shared or common underlying cognitive processes when taking these tests. It is further assumed that the information processing which a person engages in when solving a problem or answering an intelligence test item is carried out in some sort of short-term or working memory system. The final assumption (based on considerable research in the area of memory) is that the working memory system is constrained by at least three restricting properties: it has a small capacity; the limited amount of information it can hold is subject to rapid decay or loss in the absence of rehearsal; and there is a trade-off between the amount of information that can be held at one time and the amount of processing of this and other information that can be conducted at the same time.

In a test-taking problem-solving situation, a person must first encode the problem and recode it into a form that can be held in working memory. Scanning or processing of this information may allow the person to recognize the nature of the problem and the kinds of information required for its solution. If this information is available, it must be retrieved from LTM, and the actual processes involved in solving the problem may then be carried out. Note that this description avoids questions concerning the nature of such operations as recognizing the type of problem, or the task-related processes involved in solving the problem. This is deliberate but should certainly not be interpreted as suggesting that such questions are unimportant. Rather, within the context of this discussion, the more important considerations are that even a quite simple problem may entail a considerable amount of simultaneous storage, processing and retrieval of information, and that these operations are carried out in a memory system that is limited by the three properties described above. Regardless of the specific nature of the task-related operations, then, it is argued that a more fundamental determinant of a person's eventual success or failure on the problem is the extent to which he can overcome the system's limitations, and that the speed with which such processes as encoding, STM scanning and LTM retrieval are carried out is largely responsible for how well this can be done. Speed itself, of course, may be related to even more fundamental processes at the interface of brain and behavior, such as errors in the transmission of neural impulses, as hypothesized by Eysenck (1982).

The purpose of the present study is twofold. First, as mentioned, Vernon (1983a) used a sample of university students of above-average intelligence (mean WAIS IQ = 122). *S*s in the present study were vocational college students of approximately the same age as Vernon's sample but of lower average mental ability. It will therefore be possible to see whether the same degree of relationship between speed of processing and mental ability is found in a sample distinctly different with respect to level of general ability and education. In this respect, the first purpose of this study is primarily one of replication. The relationships reported by Vernon (1983a) are by no means unique (e.g. see Keating and Bobbitt, 1978; Hunt, 1976; Jensen, 1979, 1982) but are also not so well researched as to be considered established psychological phenomena. To the extent that similar relationships are observed among different samples, the results gain credence and support the empirical basis for subsequent theoretical developments.

Second, while investigating the relationship between speed of processing and mental ability *within* different samples is a useful endeavor in its own right, the present study affords the opportunity to test the hypothesis that such a relationship exists in another (perhaps stronger) manner. To the extent that one sample (the vocational college students) is of lower average mental ability than the other (university students), the former should perform more slowly and show greater intra-individual variability when presented with the same speed-of-processing tests. Thus, differences *between* groups will also be described.

Lastly, but relevant to the second purpose of this study, the vocational college sample contains an almost equal number of black and white students. Although these groups are not representative samples of the black and white populations in general, a comparison of them allows an investigation of whether the psychometric difference between these groups is also reflected in the speed-of-processing variables. Again, to the extent that one group performs at a lower average level on a psychometric test of scholastic ability, it is predicted that it will also have greater average response latencies in elementary cognitive processing tasks.

METHOD

Variables Measured and Measuring Instruments

Subjects were given six tests of speed of processing which measured their speed of STM processing, speed of retrieval of information from LTM, efficiency of STM storage and processing and simple and choice RT or speed of decision-making. Their scores on the Armed Services Vocational Aptitude Battery (ASVAB) were also obtained. Details of the specific nature of the speed-of-processing tests are reported in Vernon (1983a) and are described only briefly here. The code name by which each test is subsequently referred to is the same as in Vernon (1983a) and appears in parentheses after its name.

Speed of processing (DIGIT)

Using a test developed by Sternberg (1969), each *S* was shown a string of from 1 to 7 digits for 2 sec on the display screen of a response console connected to a Rockwell AIM 65 microcomputer. After a 1-sec interval, a single probe digit appeared and the *S*'s task was to indicate as quickly as possible whether or not the probe was a member of the string of digits that had previously appeared. The *S* responded by raising his index finger from a central 'home' button on the response console and pushing one of two other buttons, labeled 'yes' and 'no', respectively. The *S*'s *RT* was automatically recorded as the speed with which his finger was removed from the 'home' button after a probe digit appeared. (The interval between releasing the 'home' button and pushing a response button was automatically recorded as *movement time* (*MT*).) Altogether, 84 digit strings were presented, in a random order with respect to their length and whether they required a 'yes' or a 'no' response.

Speed of retrieval of information from LTM (SD2 and SA2)

This test is based on the work of Goldberg, Schwartz and Stewart (1977). The *S* was shown 26 pairs of common words* on the display screen of the same response console used in the previous test. The words were either 'same' or 'different' depending on two criteria. In the test SD2, the 26 word-pairs were literally, or physically, same or different (e.g. DOG–DOG or DOG–LOG). In test SA2, the 26 pairs of words were either synonyms or antonyms (e.g. BIG–LARGE or

*Using Thorndike and Lorge (1944), the average frequency of the words in test SD2 (and DT2) is 68.1 per 1,000,000 (or 'A' by their classification). Sixty-five per cent of the words in this test are rated 'AA' or 'A'. The average frequency of the words in test SA2 (and DT3) is 73.0 per 1,000,000. Seventy-eight per cent of its words are rated 'AA' or 'A'. In computing average frequencies, 'A' and 'AA' words were counted as exactly 50 and 100 per million, respectively, so these figures are undoubtedly underestimates.

BIG–LITTLE). In each test, half the word-pairs were the same and half were different. The S's task was to respond to the words as quickly as possible by moving his index finger from the 'home' button and pushing one of the two response buttons, now labeled 'same' and 'different'. RTs and MTs were recorded as in the DIGIT test.

Efficiency of STM storage and processing (DT2 and DT3)

This test combined the stimuli of the previous tests. The S was presented with a string of 1–7 digits (for 2 sec), which he was told to rehearse for later recall. When the digits left the screen, they were replaced by a pair of words to which the S responded on the pushbutton console as being either 'same' or 'different'. After responding, the S pressed down the 'home' button again, which triggered the appearance of a single probe digit. The S then responded 'yes' or 'no' to indicate whether the probe was a member of the string of digits that appeared before the words. The S's RTs and movement times to both the words and the digits were recorded.

In test DT2, 26 pairs of words (and 26 digit strings) were presented, and all the word-pairs were physically the same or different. In test DT3, the 26 word-pairs were synonyms or antonyms.*

Simple and choice reaction time or decision-making (RT)

This test has been used extensively by Jensen (e.g. 1979; Jensen and Munro, 1979). The apparatus for the test is a response panel with a central home button and 8 lights and buttons arranged in a semicircle of 6″ radius around the home button. The S presses down the home button, hears a warning 'beep', and waits (for a random interval of 1–4 sec) for 1 of the 8 lights to come on. As soon as one of the lights does go on, the S removes his index finger from the home button and presses the button adjacent to the light. The S is instructed to do this as quickly as possible on each of 60 trials: 15 each with either 1, 2, 4 or 8 lights/buttons exposed.

Armed Services Vocational Aptitude Battery (ASVAB)

The ASVAB is a group test measuring a diverse set of aptitudes and general information. It has 10 subtests as listed below (the subtest code names appear in parentheses after each): General Science (GS), Arithmetic Reasoning (AR), Word Knowledge (WK), Paragraph Comprehension (PC), Numerical Operations (NO), Coding Speed (CS), Auto and Shop Information (AS), Mathematics Knowledge (MK), Mechanical Comprehension (MC), and Electronics Information (EI). The whole test takes approx. 2.5 hr to administer.

Subjects and Procedure

Subjects were 106 male vocational college students, aged 17–24 yr; 56 were white and 50 black. All Ss were given the speed-of-processing tests individually in a 1 hr session. They were given these tests in the order: SD2, DIGIT, SA2, DT2, DT3, RT. ASVAB scores were taken from the Ss' files. All Ss had taken the ASVAB within 3 months of being given the speed-of-processing tests.

RESULTS

The results are presented in two main sections. The first section describes the results obtained from the present sample, while the second compares this sample's performance on the speed-of-processing tests with that of the university students tested by Vernon (1983a).

Analyses of vocational college students

Correlations between Ss' mean RTs and between intra-individual SDs on the speed-of-processing tests are presented in Table 1. All the correlations are positive and most are moderate to high. Each set of correlations was submitted to a principal factor analysis. The variables' loadings on the first (unrotated) factor extracted from each analysis are also reported in Table 1. For both mean RTs and intra-SDs, only one factor was yielded which had an eigenvalue > 1. For RTs, the first factor accounts for 65.5% of the variance [identical to the value reported by Vernon

*Vernon (1983a) used 100 pairs of words in SD2 and SA2 and 50 pairs of words in DT2 and DT3. Internal consistency reliabilities of these tests were found to be very high, warranting shortened versions in the present study.

Table 1. Correlations[a] between mean RTs and intra-individual SDs and loadings[a] of the variables on the first principal factor[b]

	SD2	DIGIT	DT2 Words	DT2 Digits	DT3 Words	DT3 Digits	SA2	RT	Factor loading
SD2		583	649	487	547	460	575	341	655
DIGIT	264		709	823	619	671	621	373	820
DT2 Words	335	606		755	767	690	704	364	875
DT2 Digits	187	691	523		698	840	705	378	893
DT3 Words	264	634	514	570		735	862	260	856
DT3 Digits	315	459	422	629	576		654	297	824
SA2	257	587	407	616	750	515		243	829
RT	153	221	133	226	212	258	147		389
Factor loading	357	796	648	800	817	696	764	271	

[a]Decimal points omitted.
[b]Correlations between RTs are above the diagonal; between intra-individual SDs below the diagonal.

(1983a)] and all the variables with the exception of RT have high loadings. For intra-SDs, the first factor accounts for 50.9% of the variance. Again, RT has a low loading compared to the other variables, as does SD2. The loadings of the other variables are all high.

Correlations between the ASVAB subtests are reported in Table 2, with the loadings of the subtests on the first principal factor. The factor loadings are generally large, with the exception of NO (a speeded, simple arithmetic test) and CS. The ASVAB was originally designed as a predictor of success in technical training, and the factor loadings obtained in this study largely reflect this design. At the same time, the high loadings of GS, WK, MK, PC and AR indicate that the test is also tapping the more general ability common to many tests of scholastic aptitude. Also reported in Table 2 are the first factor loadings of the ASVAB subtests reported by the Office of the Assistant Secretary of Defense (1982) and obtained from a representative nationwide sample ($N = 7831$). With few exceptions, there is a strong correspondence between the two sets of factor loadings; the zero-order correlation between them is 0.79 and the coefficient of congruence is 0.98. Clearly, the loadings from the larger sample are more stable and show that general scholastic aptitude (subtests GS, AR, WK, PC and MK) describes this factor at least as well as, if not better than, the more technical-knowledge subtests (AS, MC and EI). In the analyses that follow, *S*s' factor scores on the first factor obtained in this study are used as an indicator of their level of general mental ability, recognizing that this factor is not exactly a Spearman-like *g*, but also contains a certain amount of more specialized achievement variance.

For comparison with Vernon (1983a), a multiple-regression analysis was performed to investigate the overall strength of the relationship between the ASVAB and the elementary cognitive tests. *S*s' ASVAB factor scores were regressed on their mean RTs and intra-SDs, producing a shrunken R of 0.465. This is virtually identical to the R of 0.464 which Vernon (1983a) reported from the regression of Full-scale WAIS IQ scores on the same set of RT predictor variables.

Table 2. Correlations[a] between ASVAB subtests and loadings[a] on the first principal factor[b]

	ASVAB subtests											
	GS	AR	WK	PC	NO	CS	AS	MK	MC	EI	College sample factor loading	National sample factor loading[c]
GS		339	707	488	132	042	564	518	532	613	785	866
AR			360	327	206	197	299	676	565	462	626	861
WK				613	195	098	413	447	432	506	713	857
PC					211	026	466	409	332	493	631	780
NO						368	162	395	107	275	331	685
CS							−010	146	055	186	167	595
AS								365	611	584	673	664
MK									443	500	721	803
MC										527	685	774
EI											767	805

[a]Decimal points omitted.
[b]The first factor in this sample accounts for 45.4% of the variance; in the national sample, 62.8% of the variance.
[c]Based on $N = 7831$.

Table 3. Summary of regression of ASVAB factor scores on speed-of-processing variables[a]

Variable	Shrunken R	Standardized coefficient	F	Significance
DT3 Words (RT)	0.329	−0.5606	17.187	0.001
DT3 Digits (SD)	0.424	0.4235	10.201	0.002
SD2 (RT)	0.430	−0.2204	3.876	0.050
DIGIT (RT)	0.438	0.3287	5.309	0.023
DT2 Digits (SD)	0.458	−0.2499	3.351	0.070
RT (SD)	0.465	0.1206	1.803	0.182

[a]Variables are listed in their order of entry into the regression equation.

The variables contributing to this correlation are reported in Table 3. Inspection of the standardized regression coefficients indicates that storage–processing trade-off makes the strongest contribution to the prediction of ASVAB, a finding also reported by Vernon (1983a) with respect to the WAIS. Note that, due to the high intercorrelations or multicollinearity among the cognitive variables, only four of the six variables reported in Table 3 have βs significant at or beyond the 0.05 level. One of the other variables has a marginally significant β ($p < 0.10$); one is nonsignificant. The overall R of 0.465 produced by these six variables is significant beyond the 0.001 level [$F(6,99) = 5.833$].

It is of greater theoretical interest that the degree to which the RTs of the various processing tasks are correlated with the general factor of the ASVAB is directly related to the complexity of the processing tasks. The one objective index of task complexity available in the present data is the mean latency (based on $N = 106$) for each processing task. (The Pearson correlation between the mean latencies of the black and white groups is $+0.997$; $\rho = 1.00$.) Figure 1 shows the relationship between task complexity (as measured by mean latency) and the correlation of the task with the general factor of the ASVAB. (For this analysis, the black–white difference was statistically removed from the ASVAB general factor scores.) The Pearson r of $+0.96$ is an impressive value even though based on an N of 8. [For this N, an r and a ρ (Spearman's rank–difference correlation) of $+0.834$ are significant at the 0.005 level.] It is also noted that the correlation between the complexity of the eight processing variables, as indicated by their mean latencies, and the (intra-battery) 'g' loadings of these same variables is $+0.57$ in both the black and white groups. Clearly, *the more complex the processing required by the different cognitive tests, the stronger is their relationship with the general ability factor of the ASVAB.* A plausible interpretation of this finding is that the more complex tasks involve a greater variety of cognitive processing; they take more time, and afford a larger, more reliable sample of the S's general speed in various component processes such as stimulus encoding, retrieval of information from STM or LTM and storage–processing trade-off.

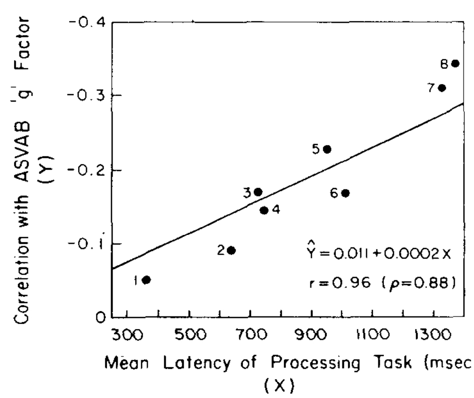

Fig. 1. Correlation of processing tasks with ASVAB general factor score as a function of task complexity as indicated by mean response latency (RT in msec) on each task in the total vocational college sample ($N = 106$). (The numbers beside the data points indicate the specific processing tasks: 1, RT; 2, DIGIT; 3, DT2 Digits; 4, DT3 Digits; 5, SD2; 6, DT2 Words; 7, DT3 Words; 8, SA2.)

Table 4. Zero-order correlations between factor scores[a] on the general factor of RT on eight cognitive processing tests and ASVAB subtest scores[b]

ASVAB subtests									
GS	AR	WK	PC	NO	CS	AS	MK	MC	EI
−0.172	−0.211	−0.125	−0.182	−0.224	−0.085	−0.111	−0.198	−0.201	−0.155

[a]The black–white difference is removed from the factor scores in this analysis.
[b]Correlations >0.164 have $P < 0.05$.

Table 4 presents the zero-order correlations between each of the ASVAB subtests and factor scores derived from the general factor extracted from the intercorrelations (with black–white variance removed) among RTs on the cognitive tests. The largest correlation is with NO, a speeded test, which at first seems to indicate that a certain amount of the overall relationship between RTs and the ASVAB is attributable to the speeded component of the ASVAB. On the other hand, the *lowest* correlation is with CS, the most strongly speeded test and the one with the smallest loading on the ASVAB general factor. Overall, there is a closer correspondence between the more general ability subtests and RT factor scores than between more specific-knowledge subtests and reaction time (e.g. subtests such as AR, PC, MK and GS have larger correlations than do EI or AS), but the pattern is by no means clearcut (MC, for example, has a relatively large correlation and WK a relatively low one).

Finally, we can look at the correlation between ASVAB general factor scores and the processing tests general factor scores (based on RT) in the total sample—a Pearson r of -0.26 ($P = 0.004$); in the black group, $r = -0.24$ ($P = 0.048$); in the white sample, $r = -0.24$ ($P = 0.038$). The fact that the shrunken multiple correlation between the processing variables and ASVAB general factor scores is 0.465 suggests that other aspects of mental speed besides just the general speed-of-processing factor are also correlated with the g of the ASVAB. RT to certain tasks, namely, the relatively more complex ones, contributes some correlation with the ASVAB g over and above the general speed factor that is common to all of the processing tasks. This finding suggests that a single speed-of-processing factor is not sufficient to account for all of the RT variance that is correlated with psychometric g. The specific nature of the processing tasks—apparently the number of different types of processes involved—also determines the degree to which *S*s' RTs to these tasks are correlated with psychometric g. But there is some ambiguity in the present study as regards this interpretation, as noted in the Discussion and Conclusions section.

Black–white differences

Differences between blacks ($N = 50$) and whites ($N = 56$), who composed the vocational college sample, were first investigated by two discriminant function analyses to determine the maximum discrimination that a given combination of tests can make between the black and white samples.

In the first discriminant analysis, the ASVAB subtests were employed as the independent (or discriminating) variables. The black and white groups differed significantly on these tests ($P < 0.001$), with a multiple correlation of 0.51 (Shrunken = 0.42) between subtest scores and population membership, and one discriminant function correctly classified 73% of the *S*s as black or white.

The second discriminant analysis investigated black–white differences on the processing tests (RTs and intra-SDs). Again, one discriminant function led to a significant ($P < 0.001$) discrimination between the groups. The overall multiple R is 0.52 (shrunken = 0.37), with 72% of the *S*s correctly classified as black or white. This discriminant analysis yields the same level of significance ($P < 0.001$) as is obtained by a MANOVA of the overall black–white difference on the processing variables. It is interesting that the discriminant analyses correctly classified *S*s as black or white to almost the same degree (i.e. about 70% correct classification) on either the ASVAB or the RT variables, even though the RT battery obviously differs markedly from the ASVAB in terms of scholastic or intellectual content. Although the official government publication of the ASVAB survey makes no comment whatsoever regarding the causality of the observed population differences, when the nationwide results on the ASVAB were announced in the general media in 1982, the most common interpretation of the large black–white difference was that it could be

Table 5. Mean RT and mean intra-SD of black ($N = 50$) and white ($N = 56$) vocational college groups on processing variables[a]

Variable	Mean RT (msec)		Difference in SD units	Mean intra-SD (msec)		Difference in SD units
	Black	White		Black	White	
SD2	981.78	924.97	0.267	249.02	242.10	0.062
	(219.47)	(206.12)		(121.62)	(102.90)	
DIGIT	647.47	627.97	0.112	210.78	235.11	−0.158
	(168.98)	(179.51)		(112.19)	(184.06)	
DT2 Words	1056.48	959.57	0.402	281.09	236.44	0.365
	(268.87)	(213.42)		(135.87)	(109.17)	
DT2 Digits	730.25	718.04	0.057	274.71	303.35	−0.185
	(215.68)	(210.59)		(132.91)	(172.67)	
DT3 Words	1375.38	1284.84	0.271	405.48	380.01	0.118
	(330.69)	(337.58)		(210.89)	(219.45)	
DT3 Digits	755.87	744.04	0.048	299.72	341.86	−0.221
	(266.73)	(225.76)		(155.38)	(217.99)	
SA2	1384.09	1351.49	0.091	413.11	401.18	0.058
	(388.66)	(377.27)		(190.16)	(216.06)	
RT	356.68	357.87	−0.030	41.85	47.45	−0.379
	(35.46)	(43.57)		(13.05)	(16.15)	

[a]Mean values appear with sample SDs in parentheses beneath them.

attributed to the fact that the ASVAB tested mainly scholastic knowledge and skills, and blacks had received generally inferior schooling.

A discriminant analysis, it should be noted, derives its maximal discriminatory power not only from the group differences on each of the separate variables, but also from their intercorrelations, such that some tests may act as suppressor variables in the optimally-weighted linear composite which discriminates between the groups. The mean black–white differences on each of the processing variables considered separately are actually quite small (and seldom significant), as seen in Table 5.

How much do the black and white groups differ on the general speed factor of all eight of the RT variables of the processing battery? Factor scores in the combined groups are scaled to a mean of 0 and standard deviation of 1. The mean black–white difference is 0.21, or only about one-third the size of the mean black–white difference (0.69) on the general factor score of the ASVAB. Although the mean difference of 0.21 is statistically nonsignificant ($t = 1.08$), it should be noted that the size of the black–white difference on the general speed-of-processing factor is almost precisely what would be predicted for any two individuals from the same population who differ as much as the mean black–white difference on the general factor of the ASVAB, because the regression of the general speed factor scores on the ASVAB factor scores is practically identical for the black and white groups, and the regression *within* groups is the same as the regression *between* groups. These relationships can be seen more easily in Fig. 2.

In terms of real time (measured in milliseconds), the mean black–white difference on the various RT tasks ranges from close to 0 msec up to nearly 100 msec, averaging about 40 msec. As shown in Fig. 3, the size of the difference bears some relationship to task complexity, as indicated by the mean latency of the task in the total sample. However, as can be seen in Fig. 4, a much stronger relationship between task complexity and mean differences is found for the vocational and university groups, which differ more markedly in general ability than do the black and white groups in this study. The rank–order correlation between the black–white differences and the vocational college–university differences in mean RT on the various processing tasks is $+0.78$ ($P < 0.025$). One can interpret these results to mean that even quite small absolute differences in the rate of information processing in elementary cognitive tasks could have considerable cumulative consequences for general intellectual development. One manifestation of these differences which would be expected over a period of time (the years of formal education, for example) is a difference in the acquisition of knowledge and problem-solving skills required for successful performance on standard tests of mental ability. However, the low degree of correlation between the RT measures and the ASVAB scores indicates that individual (and group) differences in the latter test must also reflect other major sources of variance that are not encompassed by the RT measures on the several elementary processing tasks used in this study. Whether the addition of other types of elementary processing tasks could account for more of the ASVAB variance can only be determined by further

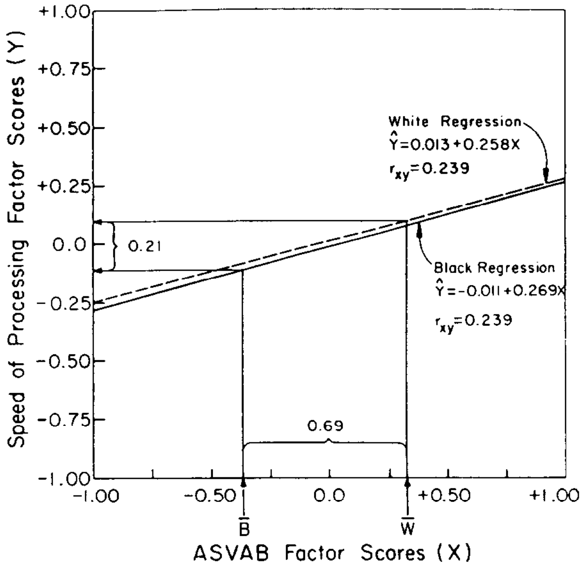

Fig. 2. The regression of the general factor scores ('general speed of information processing') of the eight processing tasks upon the general factor scores of the ASVAB, showing the highly similar regression lines for the black and white groups. The factor scores of both variables are scaled to a mean of 0 and SD of 1.

studies. Another study (Arima, 1980) of information processing rate, with high-school students, has also reported a relatively content-free mental processing task (random-forms discrimination learning) which is significantly correlated with the ASVAB and shows a significant mean black–white difference which is about 75% as large as the black–white difference on the Armed Forces Qualification Test (a subset of the ASVAB).

A motivational interpretation of the results shown in Figs 3 and 4 is contrary to certain quite well-established principles concerning the relationship between degree of motivation, or drive, and performance on tasks of varying complexity, unless one makes the rather surprising *ad hoc* assumption that the less efficiently performing group (in this study, the black group and the

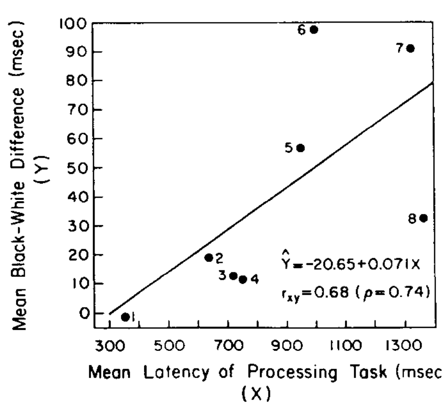

Fig. 3. Mean black–white difference (in msec) in response latency (RT) to various processing tasks as a function of task complexity as indicated by mean response latency (in msec) on each task in the combined groups. (Tasks are identified by the numbered data points, as listed in the legend to Fig. 1.)

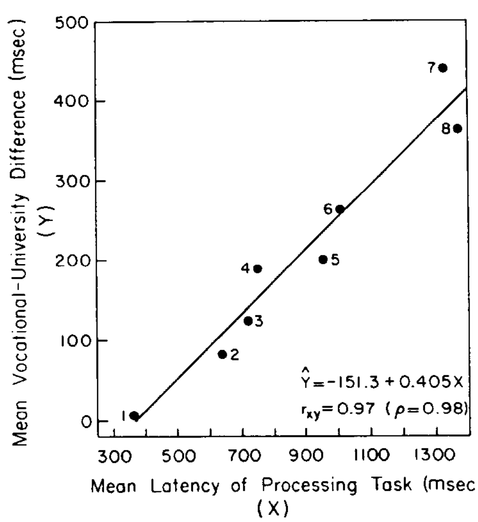

Fig. 4. Mean difference (in msec) between vocational college students ($N = 106$) and university students ($N = 100$) on various processing tasks as a function of task complexity as indicated by mean response latency (RT) on each of the tasks in the vocational college group. (The tasks are identified by the numbered data points, as listed in the legend to Fig. 1.)

vocational group) is the more highly motivated group. According to the well-known Yerkes–Dodson (1908) law, a higher level of drive facilitates performance on the simplest tasks and hinders performance on more complex tasks; in general, the optimal drive level for best performance is inversely related to task complexity. If the Yerkes–Dodson law holds for these elementary processing tasks, the observed results clearly contradict the popular explanation that the more poorly performing group performs poorly because it is relatively less motivated in the test situation.

about synonyms and antonyms. The fact that the groups do not differ significantly on the simple and choice RT task is inexplicably inconsistent with Jensen's (1979) earlier study using the very same RT task with university and vocational college groups that were presumably quite similar in their respective ability levels to the groups tested in the present study. Yet the contrasting groups in the earlier study showed quite large (over 1 SD) and highly significant mean differences on the RT variables. [Also, there was a significant ($P < 0.01$) black–white difference in choice RT, but not in simple RT, in the earlier study.] The discrepancy lies in the two vocational college samples and not in the two university samples, which are very similar on the RT variables.

DISCUSSION AND CONCLUSIONS

The findings of this study fall into two broad areas. First, within the vocational college sample, a moderate relationship between the ASVAB and the cognitive tests was found. Second, groups which differed in average level of scholastic aptitude also differed in the expected direction in their performance on the elementary cognitive tests.

With respect to the first issue, the regression of ASVAB factor scores on mean RTS and intra-SDs on the cognitive tests provided an estimate of the overall strength of the relationship between these variables. The shrunken R of 0.465 is a moderate correlation (slightly greater than 20% explained variance) and provides good replication for Vernon (1983a), which obtained the nearly identical value of 0.464 using the same cognitive variables as predictors and WAIS IQ scores as the dependent variable. Knowing the population variance of the WAIS (by definition, it is 15^2 or 225) allowed Vernon (1983a) to correct this correlation for restriction of range, leading to a corrected R of 0.688. In the present study, the vocational college sample is also considerably restricted in range (the average ratio of ASVAB subtest variances, comparing the national sample to the present sample, is 1.87), indicating that the R of 0.465 is a considerable underestimate of the correlation that could be expected in the general population.

The storage–processing trade-off—represented by test DT3—made the greatest contribution to the prediction of the ASVAB. This test (and test DT2) also entails more complex information processing than the other cognitive tests—*S*s must rehearse or hold a series of digits in memory while simultaneously deciding whether a pair of words is the same or different—and subsequent analyses showed that there was a very close correspondence between the relative complexity of the tests and their relationship with the ASVAB. Based on this, it might be more accurate to refer to the cognitive tests as tests of *complexity of processing* (rather than *speed of processing per se*). In addition, the relationship between these tests and tests of mental ability may be described as indicating that individual differences in mental ability reflect, to some extent, differences in the speed with which persons can perform *relatively complex* cognitive processes. The nature of the elementary processing tasks used in the present study, however, leaves some ambiguity concerning this interpretation, because the more complex tasks also involve prior familiarity with simple words and numbers, as contrasted with the simple and choice RT task, which does not depend upon any intellectual content whatsoever. This raises the question of whether the larger difference between groups (vocational–university and black–white) on the relatively more complex processing tests reflects the greater amount of processing they require or is attributable to differential familiarity with the numbers and words used in these tasks. The synonym and antonym comparisons require the most processing time. It is arguable that these require more 'thought', or mental processing, than, say, the scanning of digits in STM. Certainly, they must involve more cognitive activity than the simple and choice RT test. It is equally true, however, that knowledge of synonyms and antonyms is more educationally or experientially determined than the ability to attend to a panel of lights, and it is important for future research to try to resolve which of these alternatives is more responsible for the differences between the groups.*

*To gain some estimate of the familiarity of the synonyms and antonyms used in this study, a sample of 75 third and fourth grade children (ages 8 and 9 years) were given a paper-and-pencil test which asked them simply to indicate whether each of the 52 pairs of synonyms and antonyms had the same meaning or a different meaning. They did this by circling 'S' or 'D', which were printed alongside each pair of words. Overall, this sample answered 90% of the word-pairs correctly. Third graders ($N = 23$) answered 81% correctly; fourth graders ($N = 52$), 93%. This indicates a high level of familiarity with the words among a sample of children some 10 or more years younger than the vocational college students.

There is no evidence in these data that the correlation between the ASVAB and the processing tests can be attributed simply to the speeded nature of the ASVAB tests. Only two of the 10 ASVAB subtests are speeded—NO and CS. As seen in Table 4, they show the highest and lowest correlations, respectively, with the general factor of the processing tests. The most speed-dependent subtest of the ASVAB battery, CS, not only shows the lowest correlation with the general factor of the RT tests but has by far the lowest factor loading on the general factor of the ASVAB in the present sample and in the national sample (see Table 2). Moreover, partialing CS out of the correlation between NO and the RT general factor results in a partial correlation of -0.215, which is not appreciably lower than the zero-order correlation of -0.233.

Inspection of the correlations in Table 4 also indicates that ASVAB subtests such as GS, AR, PC and MK—which are among the more general ability loaded—correlate somewhat higher with RTs than do subtests such as EI and AS—which, besides general ability, also entail a considerable amount of highly specialized knowledge. To the extent that the RT tests are hypothesized to be more highly correlated with general ability or intelligence than with specific abilities, this pattern would be expected. In addition, when GS (the subtest with the highest ASVAB factor loading) is partialed out of the zero-order correlations between EI and RTs and AS and RTs, the resulting partial correlations drop virtually to zero (-0.09 and -0.04, respectively). This is similar to a finding reported by Spiegel and Bryant (1978), in which RTs correlated -0.60 with Lorge–Thorndike Intelligence Test scores, and -0.40 to -0.50 with measures of achievement. When IQ was partialed out of the achievement–RT correlations, they dropped close to zero, indicating that it was the general intelligence component of the achievement tests that accounted for the largest part of their zero-order correlations with RTs.

With respect to the second issue—group differences in mental ability and performance on the cognitive tests—this study has provided two sources of information. First, within the vocational college sample, the black and white groups were found to differ significantly on both the ASVAB and the cognitive tests. Overall, the white group obtained higher scores on the ASVAB and performed more quickly on the cognitive tests. There is a fairly close correspondence between the relative complexity of the cognitive tests and their power to discriminate between the groups, which reinforces the hypothesis that speed of *complex* information processing is most highly related to differences in mental ability.

Marked differences on the cognitive tests were found between the vocational college sample and a sample of university students. These groups have different educational backgrounds and different average levels of general mental ability, and for every cognitive test, with the exception of simple and choice RT, the university students performed significantly faster and showed less intra-individual variability. Again, there was a close correspondence between the relative complexity of the cognitive tests and the average difference in response latencies between the groups. It seems a reasonable hypothesis that the speed-of-processing differences are to some extent implicated in the average difference between the groups in scholastic aptitude and psychometric *g*.

In conclusion, the results of this study are consistent with the hypothesis that individual differences and the mean differences between groups in psychometric abilities and scholastic achievement are related to differences in the speed of information processing as measured in elementary cognitive tasks. First, there was found a moderate correlation between the ASVAB and the cognitive tasks, despite the somewhat restricted range of the vocational college sample. It was of the same magnitude as the *R* reported by Vernon (1983a) and provides good replication for that study. Second, groups differing in their average level of psychometric *g* also differed in the expected direction in their performance on the cognitive tests. The correlations within groups and the differences between groups each provides an addition to the understanding of intellectual differences. The results complement one another in a way that is consistent with the conception that differences in the speed of execution of basic cognitive processes underlie differences in general mental ability.

A potentially heuristic analogy may be drawn between cognitive processes and computers, likening some processes to the hardware and some to the software components. In terms of this analogy, we are still uncertain about the relative degrees to which psychometric *g* reflects the 'hardware' and 'software' components of cognitive processing (Sternberg and Gardner, 1982). Yet it is essential that we learn more if we are to direct our educational efforts most productively, for it seems likely that the 'software' components of intelligent behavior (the so-called metaprocesses of executive control, problem-solving strategies, predicting and monitoring one's own performance, and the like) are more readily trainable than the 'hardware' components (speed of encoding, STM capacity, retrieval of information in LTM etc.). We are even uncertain to what extent the hardware components of human information processing are amenable to special training. Only by investigating these kinds of questions with the types of laboratory techniques capable of measuring a variety of elemental cognitive processes, can we hope to make further progress toward understanding the nature of *g* and, ultimately, toward understanding the precise process components underlying various individual and group differences in human mental ability.

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