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Process Differences and Individual Differences in Some Cognitive Tasks

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This study is based on three distinct elementary cognitive tasks (ECTs) using chronometric techniques: (a) the S. Sternberg memory scan task, (b) a visual scan task which is perfectly analogous to the memory scan, except that the target digit is presented first and the subject must then scan a set of digits and indicate the presence or absence of the target digit in the set, and (c) the Hick paradigm, which involves responding to a visual stimulus (a light going "on") when the stimulus is one among sets of either 1, 2, 4, or 8 equally probable alternatives. Certain parameters of all three tasks, such as intercept and slope of RT as a function of set size, from which different cognitive processes are inferred, are compared experimentally and correlationally. Subjects were 48 university students, tested and retested on the three tasks in a counterbalanced design on two separate days to obtain the retest reliabilities needed to correct all correlations for attenuation. Subjects were also given Raven's Advanced Progressive Matrices as a measure of psychometric *g*. Parameters of the ECTs are significantly and, in some cases, quite substantially correlated with *g*. Virtually all of this correlation is due to the general factor of the various ECTs, rather than to specific processing components (independent of the general factor). The results also indicate that different ECT paradigms (e.g., visual search and memory search tasks) may yield markedly different values in terms of the group means of analogous parameters, indicating different processes, and yet not show independence of the parameters in terms of individual differences; that is, measurements of the different parameters in individuals are perfectly correlated (i.e., disattenuated correlations do not differ significantly from $r = 1$). This is found for the intercept parameter of visual and memory search. The reverse condition is also found for the other parameters (e.g., slope); that is, their mean values are nearly identical, suggesting the same processes, yet disattenuated correlations between individual differences are relatively low, or even negative, indicating different processes. Although the general factor clearly predominates, it does not completely overwhelm individual differences in various component processes that are distinct from the general factor.

In cognitive psychology, information processes are theoretical constructs which mediate between stimulus and response in cognitive tasks. Experimental psychologists attempt to identify distinct processes by manipulating task variables and by measuring the associated differences in average response. Measurements are usually obtained by chronometric techniques, because the tasks are typically

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so simple that response latency is the only feature of performance that provides reliable variance. Differential psychologists are interested in measuring individual differences in such cognitive processes, usually chronometrically, by testing all subjects under uniform conditions on simple tasks in which certain processes are hypothesized to occur. The experimental and differential approaches are necessary both for the identification and differentiation of cognitive processes and for the analysis of individual differences in task performance in terms of these processes.

The comparison of simple reaction time (SRT) and choice reaction time (CRT) affords the simplest example of process identification. (For didactic simplicity, this example of the processes involved in SRT and CRT is intentionally somewhat oversimplified [e.g., see Welford, 1980].) SRT is hypothesized to involve, say, three processes: (a) sensory lag, (b) stimulus apprehension, and (c) response execution. CRT is hypothesized to involve processes a, b, and c, as well as an additional process: (d) choice (or discrimination). There are two essential aspects of the experimental evidence for the additional process (d) in CRT. One aspect is the fact that the mean CRT is longer than the mean SRT; the other aspect is that the difference between CRT and SRT can be systematically varied by manipulating the degree of discriminability between the choice alternatives or by varying the number of alternatives. That is, the performance manifestation of a given process may vary depending on how long the process must persist or how often it must be repeated to accomplish the task demands.

The same type of comparison in support of the same hypothesis (i.e., that two tasks involve different processes) can be made on another parameter of reaction time performance, that is, the intertrial variability of RT, symbolized as σ_i and measured as the standard deviation of RT over a given number of trials. The finding that SRTσ_i < CRTσ_i can be interpreted as evidence that CRT either involves some different process(es) than those involved in SRT or involves one and the same process which differs in its degree of persistence or repetition between the two tasks, in either case producing a difference in intertrial variability of RT.

Evidence of quite another type also affords a test of the hypothesis of different processes in the two tasks, namely, the correlation between individual differences in SRT and in CRT. If the correlation, after a proper correction for attenuation, is significantly less than 1, it is presumed that SRT and CRT involve different processes, because individual differences do not maintain the same rank order on the different tasks. But what if the disattenuated correlation is *not* significantly less than 1? Would this necessarily mean that the two nominally different tasks do not involve different processes or different amounts of repetition of the same process? It would not, if the tasks differ significantly in mean or σ_i. A difference in one or both of these performance parameters must indicate a difference in processes (or process repetition), regardless of the correlation of individual differences. Assuming there are no within-subjects differences (such as learning, fatigue, drug effects, or other changes in physiological state) intervening between the subjects' performance on the two tasks, differences in task difficulty necessarily indicate the presence of process differences, either different processes or differences in process repetition or duration. A given process cannot itself discriminate between the difficulty levels of different tasks; for such a discrimination to occur, yet another process would have to be invoked. Hence, a difference in task difficulty, as reflected by increased response latency, necessarily indicates some kind of process difference. However, two tasks can differ in the processes they elicit and yet show a perfect correlation between individual differences. The theoretical explanation is that the different processes, although distinct, are both perfectly correlated with some more fundamental process or property of the nervous system in which there are individual differences.

As a simple mechanical analogy, imagine three distinct machines (analogous to *processes*), labeled *a, b, c,* that perform different jobs which require different amounts of time. Some jobs involve *abc*, some involve only *ab*, or *ac*, or *bc*, and some involve only *a* or *b* or *c*. If jobs requiring the operations of two or three machines must be done sequentially by the machines, some jobs will take longer than others. Experimental manipulations of the job demands and the differing amounts of time it takes to perform the various jobs could reveal the actions of any one or any combination of three distinct machines. But if the three machines are all connected by various-sized cogwheels in a gear-train driven by a single constant-speed motor, the speeds of their particular operations, though differing, will all be perfectly correlated. Across *different sets* (analogous to *individual differences*) of these machines, the only reliable source of (individual) differences would arise from consistent differences in the speed of the single-drive motor in each set.

The observation that two operationally distinct tasks can involve different cognitive processes, as indicated by large mean differences (or σ_i differences) in certain performance parameters, and yet can show highly or perfectly correlated individual differences, absolutely proves the hierarchical nature of cognitive processes. Hence, the theory of a hierarchical organization of mental abilities does not depend exclusively on a particular model of factor analysis. A hierarchical organization of processes is an inescapable theoretical necessity in explaining high or perfect correlations between tasks (i.e., particular parameters of task performance) that clearly differ in their process demands.

If two or more different processes, *a* and *b,* can occur simultaneously rather than sequentially, the two processes might require no more time than either one alone, and so, conceivably, two different tasks, one involving only process *a* and the other involving both *a* and *b,* might not differ in mean response latencies. Yet, they could show a less than perfect correlation of individual differences, which would indicate the presence of different processing entering into the two tasks. The only moot case is one in which (a) there are no parameters of performance that differ between two tasks and (b) individual differences in every performance parameter are perfectly correlated across the two tasks. In such a case, which is probably rare or even nonexistent, one can presume probabalistically, but cannot prove, that performance on the two tasks does not involve different processes or different amounts of repetition of the same process(es). Proof of different processes is impossible in this case because there is always the possibility, however improbable, that the durations of different processes, if simultaneous, might perfectly coincide, and that the different simultaneous processes are perfectly correlated with one another because they both are also perfectly correlated with some other, more basic, process.

The foregoing formulation of process differentiation is really the central theoretical issue in an important pioneer study by Chiang and Atkinson (1976), although these investigators did not offer any very explicit theoretical basis for their analysis. Essentially, they compared performances on two distinct elementary cognitive tasks (ECTs): *Visual Search* (VS) and *Memory Search* (MS). The subjects were 34 Stanford University undergraduates.

In VS, an ECT originally proposed by Neisser (1967), a single target letter is presented briefly, then removed, and followed by a horizontal, simultaneous display of 1 to 5 consonant letters. The subject's task is to decide whether the target letter is in the display set. The subject responds *YES* or *NO* by pressing keys so labeled, and reaction time (RT) and errors are recorded on each trial.

In MS, known as the Sternberg (1966) paradigm, a series of 1 to 5 consonant letters is displayed (sequentially in the Chiang and Atkinson study) for the subject to study briefly, then is removed and is followed by a single target letter. The subject must decide whether the target letter was in the displayed set, and RT to the *YES* or *NO* response key (as well as response errors) is recorded on each trial, exactly as in the VS procedure.

In both paradigms, it is found that RT increases linearly as a function of set size (SS), and RT is always longer for negative than for positive responses. The main performance parameters are the *intercept* and *slope* of the regression of RT on SS. The correlation (r) between RT and SS indicates the goodness of fit of the data points to a linear trend. The results of the Chiang and Atkinson study are shown in Figures 1 and 2. The regression equations shown in Figures 1 and 2 were calculated from the RT data provided in Table 1 of the Chiang and Atkinson article, so they could be compared with the analogous regressions computed on the data of the present study. Chiang and Atkinson offer no theoretically satisfactory explanation of why they omitted set size 1 in calculating the regressions reported in their study (p. 665), which are: for VS, RT = 413 + 48S (r = .987); for MS, RT = 435 + 42S (r = .997). The omission of set size 1 in calculating the regression parameters affects Chiang and Atkinson's conclusions in theoretically important ways. There is no significant difference (at α = .05) between the slopes of the VS and MS tasks, but their intercepts differ significantly ($p < .05$). Also, individual differences are correlated across VS and MS: Without correction for attenuation, r = .968 for intercepts and .832 for slopes. (As corrected by the split-half reliability, these correlations become 1.01 and .92, respectively; as corrected by the test-retest reliability, the correlations are both slightly greater than 1.)

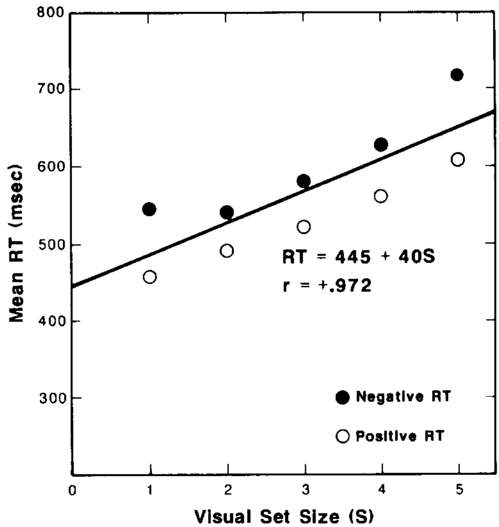

FIG. 1. Mean RT for positive and negative responses as a function of set size in the visual search (VS) task. The regression equation and r are based on the means of the positive and negative RTs on set sizes 1 to 5 (Data from Chiang & Atkinson [1976], Table 1.)

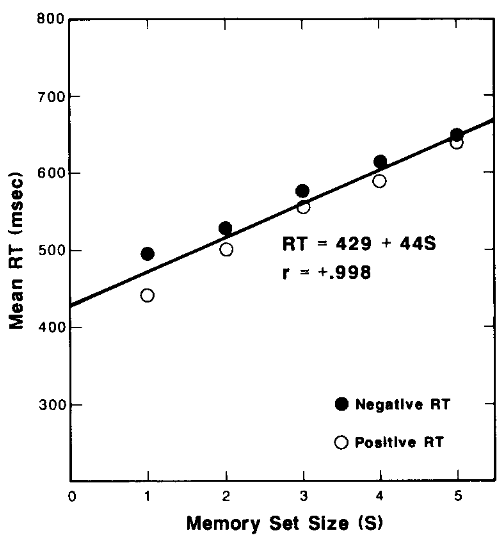

FIG. 2. Mean RT for positive and negative responses as a function of set size in the memory search (MS) task. The regression equation and r are based on the means of the positive and negative RTs on set sizes 1 to 5. (Data from Chiang & Atkinson [1976], Table 1.)

These two paradigms and the reported results derive their considerable theoretical importance from the fact that both the intercept and slope parameters are hypothesized to reflect different processes (or combinations of processes) in the VS task than in the MS task. The task demands of VS and MS obviously differ. In VS there is minimal demand on memory and the display set must be visually scanned to determine the presence or absence of the single target. In MS the display series must be encoded in short-term memory (STM) and later the STM must be scanned to determine the presence or absence of the single target. Following the theoretical analyses of Sternberg (1966, 1969, 1975) and of Chiang and Atkinson (1976), the information-processing components of VS and MS reflected by the intercepts and slopes of the regressions of RT on visual or memory set size are as follows:

	VS Task	*MS Task*
Intercept:	Binary decision + response production	Stimulus encoding + binary decision + response production
Slope:	A single stimulus encoding + a single comparison	A single comparison

In other words, VS and MS differ only in the stimulus-encoding process as it is reflected in both the intercept and slope. The intercept reflects encoding for MS but not for VS. The slope reflects encoding for VS but not for MS. Hence, differences between VS and MS in intercepts and slopes must reflect only differences in stimulus encoding. A corollary of this model is that, on comparison of RT *intercepts*, VS < MS; on comparison of RT *slopes*, VS > MS.

Chiang and Atkinson's data fit this model for both intercepts and slopes (although the slope difference is nonsignificant), but *only* if the regressions are based on set sizes 2 to 5. When the regressions are based on *all* set sizes (1 to 5), the results are *opposite* to the model, for both intercepts and slopes.

In any case, the fact that the correlations between VS and MS for both intercept and slope are almost as high as the reliability coefficients of these parameters virtually precludes the possibility of obtaining reliable measurements of individual differences in stimulus-encoding speed by the subtraction method (i.e., RT intercept on MS *minus* RT intercept on VS; or RT slope on VS *minus* RT slope on MS). This follows from the reliability of a difference score (say, $x - y$), which is

$$r_{(x-y)(x-y)} = \frac{r_{xx} + r_{yy} - 2r_{xy}}{2(1 - r_{xy})} .$$

(In the case of Chiang and Atkinson's data, the reliability of individual measurements in encoding speed obtained by the subtraction method would be $-.41$ for the intercept difference and $+.41$ for the slope difference.)

Chiang and Atkinson raise the main question of theoretical interest as follows: "It might be argued that performance on these search tasks is related to a general factor, speed, and that it is not useful to break down performance into several component processes or to distinguish between parameters of these processes" (p. 668). They go on to claim that the findings of their experiment refute this argument. Their refutation is based on two points: (a) Low or negative correlations were obtained between intercept and slope of the same task (VS, $r = +.107$; MS, $r = -.286$), which they interpret as indicating that search speed is unrelated to speed of response production or of binary decision; (b) the total number of response errors was significantly ($p < .01$) correlated ($-.531$) with slope, but not with intercept ($-.157$) or mean RT ($-.349$), suggesting that error rate is differentially related to separate processes.

Unfortunately, both points of their claimed refutation are methodologically fallacious. (1) The true correlation between intercept and slope derived from the same data is spuriously decreased (even to the point of being negative) by pure artifact, due to the necessarily negative correlation between the errors of measurement in the two parameters. The very same measurement errors that increase the slope necessarily decrease the intercept, and vice versa. Marascuilo and Levin (1983, p. 161) give the formula for the correlation between intercept and slope, calculated from the same data, when the true-score correlation is zero. In the case of Chiang and Atkinson's data, this correlation is $-.905$. Hence, the only correct method for obtaining the correlation between intercept and slope is to use two experimentally independent sets of measurement, say, sets X and Y, and correlate intercept X with slope Y and intercept Y with slope X, and then average the two correlations. Only with experimentally independent measurements will the intercept and slope not share the same negatively correlated errors of measurement. (2) The fact that the correlation between slope and errors is significantly different from zero whereas the correlations between intercept and errors and between mean RT and errors are not significantly greater than zero is irrelevant. The wrong hypothesis was tested. The hypothesis of interest in this case is whether the three correlations differ significantly from one another. The proper test of this hypothesis, given by Hotelling (1940), indicates that the differences between the three correlations do not even approach the .05 level of significance.

A more general criticism of Chiang and Atkinson's approach to the question raised in their above-quoted statement stems from their not distinguishing between experimental and correlational evidence as criteria for differences in processes between the regression parameters of the VS and MS tasks, and therefore not recognizing the hierarchical organization of processes, as explicated previously in this introduction.

It is not the purpose of the present study to replicate the Chiang and Atkinson study specifically, but to take seriously the theoretically interesting question the authors pose in their statement quoted above, and to present a study that is methodologically better designed to throw some light on it.

METHOD

Subjects

Subjects were 48 university undergraduates who were paid for participation.

Test of Psychometric *g*

The Raven Advanced Progressive Matrices (APM), a 36-item test of nonverbal reasoning, was used as a measure of general intelligence, or psychometric *g*. A previous study (Vernon, 1983) in this laboratory, with 100 subjects from the same subject pool, showed that the APM is more highly loaded on the *g* factor of the Wechsler Adult Intelligence Scale (WAIS) than is any one of the 12 WAIS subtests.

The APM was given to each subject individually. After the standard instructions, subjects were given preliminary practice on the first 12 items of the Standard Progressive Matrices. Subjects were urged to attempt every item of the APM and to take all the time they needed; as inducement to take sufficient time, their pay was prorated for the total time they spent in taking the test.

Elementary Cognitive Tasks

Apparatus. The same apparatus was used for the VS and MS tasks. The stimuli were displayed on an IBM monochrome monitor, at eye level, about 2 ft in front of the sitting subject. The subject's response console was a 20-cm square metal box with its top side pitched at a 15° angle for easy access to three microswitch round pushbuttons of 1-in diameter placed in the form of an equilateral triangle, with 10 cm between the centers of the three pushbuttons. The button nearest the subject is the "home" button. Closely above each of the two top buttons are large-print labels: YES on the left and NO on the right. The task was subject paced, each trial initiated by the subject's pressing the home button with the index finger of the preferred hand. The response console is interfaced with an IBM-PC. The entire sequence of trials was programmed on a diskette and the subject's reaction time (RT), movement time (MT), and errors on each trial were recorded on a diskette.

The response console for the Hick paradigm is a 33 cm × 43 cm flat-black metal box with the top side pitched at a 20° angle. On the surface of the box is a semicircle (with 15-cm radius) of eight underlighted, transluscent, green plastic ¾-in microswitch pushbuttons. At the exact center of the semicircle, nearest the subject, is a "home" button identical to that used on the subject's console for the VS and MS tasks. Flat-black plastic overlays can be clipped onto the face of the console so as to expose either 1, 2, 4, or 8 of the green pushbuttons that form a semicircle above the home button. The console is interfaced with an IBM-PC. Pressing the home button initiates a trial. The entire sequence of stimuli is programmed and the subject's RT and MT on each trial were recorded on a diskette.

Design

Each subject reported to the lab on three separate days, all within a period of 1 week. Subjects were randomly assigned in equal numbers ($N = 12$) to one of four groups to completely counterbalance the order of administering the VS and MS tasks, as follows:

Group	*Day 1*	*Day 2*
1	VS–MS	VS–MS
2	MS–VS	MS–VS
3	VS–MS	MS–VS
4	MS–VS	VS–MS

In each group on Days 1 and 2, the Hick task was administered prior to the VS and MS tasks. The Raven APM was administered on Day 3. Although counterbalancing the order of administration of the VS and MS conditions is, of course, required for the proper interpretation of the experimental analysis, it is a suboptimal procedure for the correlational analysis of individual differences. But there is no way out of this bind, short of having large-enough sample sizes to permit separate correlational analyses within each of the four groups. Combining the four groups used for counterbalancing order effects, as is done here, adds to the component of variance due to subject × order interaction, and in the present correlational analyses, this component, in effect, becomes part of the measurement error that attenuates correlations to some unknown degree.

Procedure

Hick Task. After 10 practice trials on the 8-button task, subjects were given 15 trials on each of the 1, 2, 4, and 8-button tasks, always in that order. On each trial, the target light was a preprogrammed random selection from the available set sizes, either 1, 2, 4, or 8 alternatives, with the restriction that each light in a given set size was selected an equal number (± 1) of times in the 15 trials. A trial was initiated by the subject's pressing the home button. After an interval of 1 s, a preparatory signal (a 1-s "beep") sounded, followed by a continuous random interval of from 1 to 4 s, after which the reaction stimulus appeared—one green button in the displayed set would light up. The subject's task was to touch the lighted button as quickly as he or she was able, which turned out the light.

RT is the interval between the onset of the reaction stimulus and release of the home button; MT is the interval between release of the home button and touching the lighted button. The subject's RT (MT) score for each set size is the median of 15 trials. The subject's overall RT (MT) is the mean of the four medians. The intraindividual (intertrial) variability of RT (MT), symbolized σ_i, is measured by the standard deviation of RT (MT) over 15 trials at each set size; the subject's overall σ_i is the square root of the mean of the variances on each of the four set sizes.

Visual Search (VS) Task. The subject is given 16 practice trials, with the option of an additional 16 practice trials if either the subject or the tester feels that the basic requirements for task performance have not been mastered. There are 84 test trials, 12 for each set size 1 through 7. The order of presentation of the various set sizes was the same programmed random order for all subjects. The digit sets are all composed of the digits 1 through 9, selected and ordered at random except that no digit is repeated in a given set. For each set size, 6 trials call for a *YES* response (i.e., the set contains the target digit) and 6 trials call for a *NO* response (i.e., the target digit is not contained in the set). The sequence of *YES* and *NO* responses is in the same random order for all subjects.

The VS task sequence is as follows:

1. To initiate a trial, subject presses down the home button and keeps it down.
2. 1-s delay.
3. Target digit appears on display screen for 2 s.
4. Screen goes blank for a continuous random interval of 1 to 4 s.
5. A series of digits of a given set size (from 1 to 7) simultaneously appears horizontally on the screen. Set size is randomized across trials and is the same for all subjects.
6. The series remains on the screen until subject presses either the *YES* or the *NO* pushbutton. (RT is the interval between onset of the series and subject's release of the home button. MT is the interval between release of the home button and subject's pressing the *YES* or *NO* button.)
7. Instantly following the subject's *YES* or *NO* response, the word "Correct" or "Incorrect" appears on the screen for 2 s.

The number of incorrect responses was automatically recorded. The subject's RT (MT) for a given set size is the median of 12 trials; overall RT (MT) is the mean of the medians over all set sizes. Intraindividual variability (σ_i) is the standard deviation (*SD*) of the subject's RT (MT) across trials within a given set size; the subject's overall σ_i is the mean of the *SD*s across all set sizes.

Memory Search (MS) Task. This is exactly the same as the VS task except that the order of presentation of the single target digit and the digit series is reversed. All performance parameters on MS are obtained in exactly the same way as on VS.

RESULTS

Descriptive Statistics on the Visual Search, Memory Search, and Hick Paradigms

All of the descriptive data on these paradigms are based on the average of the Day 1 and Day 2 data for each subject ($N = 48$). Any effects of order of administration of VS and MS are completely counterbalanced in the experimental design.

Visual Search and Memory Search. These two paradigms must be considered together for comparative purposes. The basic statistics on RT and MT are presented in Tables 1 and 2. Note that the mean MT is less than half the mean RT, and their *SD*s show a corresponding difference. Because the phenomenon of main theoretical interest, namely, the increase in response latency as a function of set size, is strikingly manifested in the RT data and not at all in the MT data, the analysis is focused on RT. In general, in all of the chronometric studies in which a home button has been used in order to separate RT and MT, these two variables are found to be markedly distinguishable with respect to so many experimental and individual differences variables as to underline the importance of measuring these two aspects of performance separately.

The main features of the VS and MS data can be seen more easily in Figures 3

TABLE 1
Mean RT and Standard Deviation (in ms) and Mean Percentage of Errors for Positive and Negative Responses as a Function of Set Size for the Memory Search and Visual Search Tasks (N = 48)

	Negative			Positive		
Set Size	Mean RT	*SD*	Mean % Errors	Mean RT	*SD*	Mean % Errors
			Memory Search Task			
1	481	115	2.78	439	103	6.08
2	498	114	3.67	452	88	4.00
3	519	119	3.13	484	107	9.20
4	542	116	2.43	501	113	5.38
5	569	150	4.33	523	99	8.33
6	595	182	7.12	584	152	11.28
7	599	212	5.55	595	150	14.75
Mean	543.29	144.00	4.14	511.14	116.00	8.43
			Visual Search Task			
1	532	118	6.77	514	102	10.07
2	521	103	5.55	500	93	3.82
3	547	125	3.13	509	102	7.63
4	561	110	4.87	516	97	5.90
5	614	166	5.03	526	111	6.42
6	644	181	6.42	590	127	9.72
7	734	218	5.55	601	138	8.33
Mean	593.29	145.86	5.33	536.57	110.00	7.41

TABLE 2
Mean MT and Standard Deviation (in ms) for Positive and Negative Responses as a Function of Set Size for the Memory Search and Visual Search Tasks (N = 48)

	Negative		Positive	
Set Size	Mean MT	*SD*	Mean MT	*SD*
		Memory Search Task		
1	205	87	199	66
2	202	73	204	71
3	207	72	210	83
4	205	73	201	70
5	202	71	209	73
6	204	77	226	94
7	209	80	224	82
Mean	204.86	76.14	210.43	77.00
		Visual Search Task		
1	222	81	216	69
2	205	89	212	72
3	208	74	210	62
4	202	72	196	54
5	212	80	206	63
6	218	82	215	68
7	226	73	223	74
Mean	213.29	78.71	211.43	66.00

and 4. Despite the many differences in apparatus and procedure, the present data on VS and MS, as shown in Figures 3 and 4, bear a remarkably close resemblance to the VS and MS data of Chiang and Atkinson as shown in Figures 1 and 2. Almost exactly the same pattern of differences between VS and MS was found by Ananda (1985, pp. 36–38), using set sizes of 1 to 7 digits with 76 elderly subjects (mean age, 68 years). The differences between VS and MS that first strike the eye in these figures are apparently a quite robust phenomenon, for in all three studies, although each used different apparatuses and procedures, one sees essentially the same picture. In each of these studies, the RTs of the negative responses in VS show a distinctive departure from the near-perfect linearity of the corresponding RTs in MS. Positive RTs, however, are quite linear in both VS and MS. Omitting set size 1 considerably improves the fit to a linear trend for VS, but has virtually no effect on the linearity of MS. Averaging the RTs of the positive and negative responses at each set size permits another view of the RT differences between VS and MS, as shown in Figure 5.

Before inquiring about the statistical significance of the observed differences,

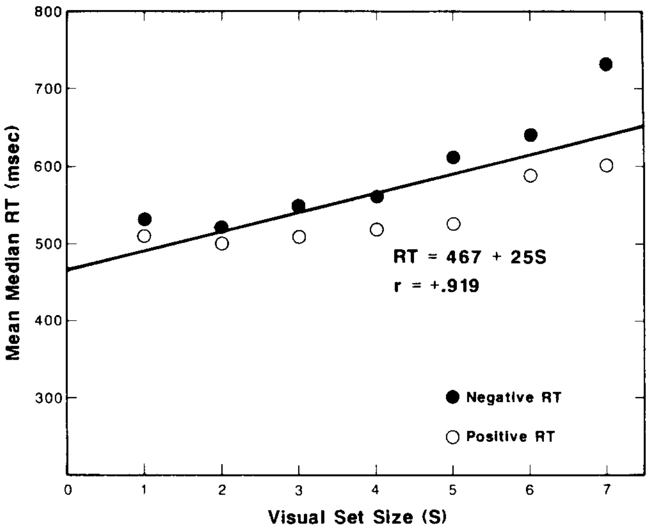

FIG. 3. Mean RT for positive and negative responses as a function of set size in the VS task. The regression line and regression equation are based on the means of the positive and negative responses on set sizes 1 to 7.

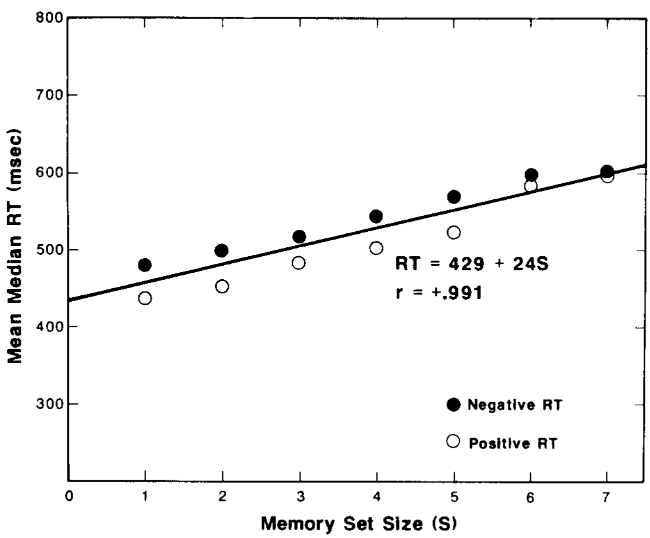

FIG. 4. Mean RT for positive and negative responses as a function of set size in the MS task. The regression line and regression equation are based on the means of the positive and negative responses on set sizes 1 to 7.

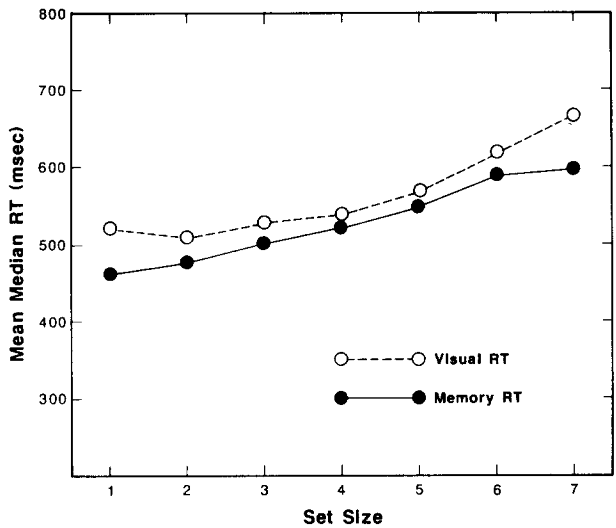

FIG. 5. Overall mean RT (i.e., the average of positive and negative responses) as a function of set size on VS and MS.

we should also look at the regression parameters. These were calculated for each subject. The means and *SD*s of the intercept and slope and the index (r) of goodness of fit to a linear trend are shown in Tables 3 and 4 for RT and MT, respectively. Again, we see that MT does not reflect the effect of set size, as shown by the practically negligible slope parameter, which overall does not differ significantly from zero (t = 1.48). Also, in every condition, the intercept of MT is less than half that of RT.

Hick Paradigm. The combined data of Day 1 and Day 2 on the Hick paradigm are summarized in Table 5. Two comments are in order: (a) For these data, the slope of MT, although only 6 ms/bit, is greater than is generally found in many other studies, in which the typical slope is only about 1 ms/bit (Jensen, 1987). (b) Whereas median RT has a more highly linear fit to bits (r = .971) than to set size (r = .866), intraindividual variability, $RT\sigma_i$, is more linearly related to set size (r = .991) than to bits (r = .974). This difference between median RT and $RT\sigma_i$ is a highly consistent phenomenon in all studies of the Hick paradigm (Jensen, 1987).

Direct comparisons of the actual values of the Hick parameters with the corresponding VS or MS parameters would not be meaningful in view of the marked differences between these paradigms in apparatus and procedures.

Differences between Visual Search and Memory Search

Tables 6 and 7 show the mean differences between VS and MS for MT and RT,

TABLE 3
Mean and Standard Deviation of Regression Parameters (Intercept and Slope) for Regression of Median RT (in ms) on Set Size (N = 48)

	Intercept		Slope			
Condition	***M***	***SD***	***M***	***SD***	r^a	r^b
Memory negative	458	102	21	24	.993	.989
Memory positive	401	86	28	15	.982	.981
Visual negative	462	83	33	21	.929	.963
Visual positive	471	85	16	11	.859	.927

[a]Pearson correlation of mean RT (based on 48 *S*s) with set size for set sizes 1–7.
[b]Pearson correlation of mean RT (based on 48 *S*s) with set size for set sizes 2–7.

respectively. Also shown are the correlations between VS and MS on each variable and (in parentheses) the correlation corrected for attenuation, based on the test–retest reliability of each variable. The t tests for correlated variables and their exact two-tailed p values serve mainly as an index of the relative differences between VS and MS on the various RT (or MT) variables derived from these tasks.

For MT (Table 6), the mean VS–MS differences are very small and generally nonsignificant, and the disattenuated correlations between VS and MS (with the exception of the slope parameter) are not significantly different from 1. (Lord [1957] provides a test of the significance of the difference between a disattenuated correlation and 1, but there is no need for this test if the disattenuated $r \geq 1$.) It appears that VS and MS do not differ with respect to MT and that different processes in the two tasks need not be hypothesized to account for the MT results. In view of this general picture, it is hard to know what to make of the highly significant (p = .001) difference in mean MTσ_i. The VS–MS differences

TABLE 4
Mean and Standard Deviation of Regression Parameters (Intercept and Slope) for Regression of Median MTs (in ms) on Set Size (N = 48)

	Intercept		Slope		
Condition	***M***	***SD***	***M***	***SD***	r^a
Memory negative	203	79	0	7	.333
Memory positive	193	68	4	8	.849
Visual negative	207	88	2	10	.360
Visual positive	208	68	1	7	.208

[a]Pearson correlation of mean RT (based on 48 *S*s) with set size for set sizes 1–7.

TABLE 5
Means and Standard Deviation (in ms) of Variables in the Hick Paradigm

Condition		Median RT		Median MT		$RT\sigma_i$		$MT\sigma_i$	
Set Size	**Bits**[a]	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
1	0	282	37	207	45	35	18	84	41
2	1	299	38	209	46	42	22	101	45
4	2	315	35	213	43	47	15	112	38
8	3	319	34	226	42	61	38	119	59
Intercept[b]		272	42	198	50				
Slope[b]		13	8	6	8				
Fit (r)[b,c]		.971		.922					

[a]Bit = $\log_2$ set size.
[b]Regression of RT (MT) variable on bits.
[c]Computed on the above means, not on individuals.

TABLE 6
Correlated *t* Tests of MT Differences (in ms) between Visual Search and Memory Search Variables

MT Variable	Mean Difference[a]	Correlation[b]	t[c]	Two-Tailed p
Median: set size 1	16.7	.786 (1.09)	2.68	.010
set size 2	6.7	.793 (1.13)	1.10	.275
set size 3	0.4	.762 (1.09)	0.07	.945
set size 4	−4.6	.816 (1.14)	−0.83	.413
set size 5	1.0	.813 (1.12)	0.17	.862
set size 6	0.5	.755 (1.07)	0.07	.945
set size 7	6.6	.795 (1.25)	1.00	.324
Mean median	2.8	.829 (1.14)	0.53	.599
Intercept of medians	9.9	.779 (1.07)	1.60	.116
Slope of medians	−1.4	.257 (.60)	−1.52	.136
σ_i: set size 1	37.5	.745 (1.21)	2.63	.012
set size 2	25.2	.728 (1.05)	1.83	.074
set size 3	31.6	.802 (1.49)	2.19	.034
set size 4	18.1	.763 (1.01)	1.28	.207
set size 5	22.3	.847 (1.03)	1.88	.066
set size 6	34.7	.766 (.92)	1.84	.072
set size 7	77.5	.797 (.98)	4.09	<.001
Mean σ_i	31.6	.902 (1.06)	3.41	.001

[a]All differences are *Visual* minus *Memory*.
[b]Correlations in parentheses are corrected for attenuation. The Spearman–Brown boosted test–retest reliability coefficients used in the correction are shown in Appendix A.
[c]Degrees of freedom = 47.

TABLE 7
Correlated t Tests of RT Differences (in ms) between Visual Search and Memory Search Variables

RT Variable		Mean Difference[a]	Correlation[b]	t^c	Two-Tailed p
Median:	set size 1	62.2	.857 (1.02)	7.58	<.001
	set size 2	30.2	.903 (1.05)	4.95	<.001
	set size 3	26.2	.899 (.99)	3.60	.001
	set size 4	16.3	.871 (1.00)	2.06	.045
	set size 5	24.8	.917 (1.03)	3.40	.001
	set size 6	26.6	.848 (.93)	2.21	.032
	set size 7	63.0	.783 (.88)	4.00	<.001
Mean median		29.6	.914 (1.00)	4.43	<.001
Intercept of medians		36.3	.832 (1.00)	4.87	<.001
Slope of medians		−0.2	.503 (.65)	−0.09	.928
σ_i:	set size 1	−8.4	.663 (1.74)	−0.79	.4443
	set size 2	−0.9	.577 (.99)	−0.08	.937
	set size 3	6.0	.792 (1.84)	0.52	.609
	set size 4	−3.3	.544 (.89)	−0.31	.758
	set size 5	3.0	.676 (1.09)	0.35	.729
	set size 6	19.0	.749 (1.18)	2.02	.049
	set size 7	58.0	.664 (.94)	5.08	<.001
Mean σ_i		12.7	.873 (1.09)	2.04	.047

[a]All differences are *Visual* minus *Memory*.
[b]Correlations in parentheses are corrected for attenuation. The Spearman–Brown boosted test–retest reliability coefficients used in the correction are shown in Appendix A.
[c]Degrees of freedom = 47.

in MTσ_i are consistently positive across all set sizes, and so this one kind of difference appears to be a real phenomenon and not just a fluke. But why MT should show greater intraindividual variability on VS than on MS is a puzzle. If subjects continued their search of the displayed set after releasing the home button, one should expect both the median MT and MTσ_i to show an increasing trend as a function of set size, but no such trend is evidenced over set sizes 1 to 6. The disattenuated correlations between VS and MS on the σ_i variable are essentially 1. Other studies (e.g., Ananda, 1985, p. 43; Paul, 1984, p. 36) have found that mean MT is remarkably constant across a wide variety of cognitive tasks and experimental conditions employing the same chronometric apparatus, whereas mean RT varies markedly across different tasks. This is another good argument for separating the measurment of RT and MT.

For RT (Table 7), the mean VS–MS differences are quite another story. All of the differences in median RT and the intercept are quite significant, but the difference in slopes is absolutely nil (−0.2 ms/set size). Despite all these quite large and significant differences in mean RT between VS and MS, the two tasks are very highly correlated on every variable except slope. With that one exception, the disattenuated correlations are all about 1. Hence, one would infer distinct processes in VS and MS on the basis of the mean differences, but some common source of individual differences in the distinct processes.

As for RTσ_i, the differences are small (with the exception of set sizes 6 and 7), and show no regular pattern. And, on σ_i, the disattenuated VS and MS correlations are virtually 1, again indicating a common source of individual differences in the two tasks.

Fit of VS and MS Differences to the Theoretical Process Model

The process model proposed by Chiang and Atkinson, following Sternberg, predicts that, for the RT intercept, V < M; and for RT slope, V > M. The model does not accord with the present data, which, in fact, show a significantly ($p < .001$) opposite result for intercept (i.e., V > M) and an utterly nonsignificant ($p = .928$) difference for slope. Chiang and Atkinson found the same thing for both intercept and slope. Their data agreed with the model only on intercept, provided set size 1 was omitted in calculating the regression equation. In the present data, omitting set size 1 does not materially alter the picture, nor does calculating the regression only on set sizes 1 to 5 or on set sizes 2 to 5, to match Chiang and Atkinson's analysis. Under every one of these conditions, the model fails to fit the data. When the regressions are computed separately for positive and negative responses, the intercept differences both remain opposite to the model, whereas the slope difference agrees with the model for negative responses and is opposite to the model for positive responses. The same comparisons made on the Chiang and Atkinson data give the exact same result. In sum, the model cannot be claimed to fit the data of either study.

Do the MT regression parameters show any sign of agreement with the model? No. Both the MT intercept and slope differences are nonsignificant and, to boot, they are both in opposite directions to what would be predicted by the model. Hence, every aspect of these data is contrary to the theoretical process model. This finding should not be interpreted to mean that there are not differences in processes between VS and MS, but only that the hypothesized model of the process differences is most likely wrong.

Correlations between Homologous VS, MS, and Hick Regression Parameters

VS × MS Correlations. Probably the best way to appreciate the degree of correlation between VS and MS on a given parameter is to look at all of the six possible correlations between VS and MS on Days 1 and 2. These are shown in Table 8, along with the maximum possible correlation between VS and MS across days. With the single exception of RT slope, none of the correlations between VS and MS is significantly smaller than the theoretically maximum

TABLE 8
Correlations between Visual (V) and Memory (M) Search Variables Obtained on the Same Day and across Different Days for Reaction Time and Movement Time (N = 48)

Variable	Same Day[a]		Across Days				Maximum Correlation[b]
	V_1M_1	V_2M_2	V_1M_2	M_1V_2	V_1M_2	M_1M_2	$\sqrt{V_1V_2 \times M_1M_2}$
				Reaction Time			
Mean median	.848	.894	.855	.792	.832	.858	.845
Intercept	.709	.790	.715	.664	.673	.748	.709
Slope	.352	.574	.379	.368	.527	.754	.630
σ_i	.783	.841	.758	.531	.705	.629	.666
				Movement Time			
Mean median	.611	.846	.669	.571	.498	.662	.574
Intercept	.598	.817	.566	.557	.494	.679	.579
Slope	.390	−.211	.225	.292	.232	.321	.273
σ_i	.815	.856	.820	.694	.709	.782	.745

[a]Day 1 and Day 2 test sessions are indicated by subscripts 1 and 2.
[b]This is the theoretically maximum possible correlation between V and M across Days 1 and 2.

correlation. Correlations between VS and MS when taken on the *same day* generally tend to be negligibly higher than the correlations *across* days.

It seems a reasonable inference from the correlations in Table 8 that, with the clear exception of RT slope, the VS and MS tasks, however they may differ in their component processes, share entirely the same common source of individual differences on each of the parameters (median, intercept, σ_i) for both RT and MT.

VS × MS × Hick Correlations. Table 9 shows the raw correlations and disattenuated correlations between the three tasks for medians, intercepts, and slopes. Section A merely reaffirms the conclusions drawn from Table 8. Sections B and C clearly indicate that the search paradigms both have some variance in common with the Hick paradigm on the median RT and RT intercept, although even the disattenuated correlations are not large, indicating that the search variables and Hick variables have considerable specificity, which implies different processes in the two types of tasks. This is especially striking with respect to RT slope, which is *negatively* correlated between both of the search tasks and the Hick task. The interpretation of the slope parameters in all tasks as a *general* measure of individuals' rates of information processing would obviously be a gross oversimplification, considering that the slope measures are even *negatively* correlated across different paradigms.

TABLE 9
Correlational Comparison of Visual Search, Memory Search, and Hick Paradigms

A. Correlation (r) between Visual and Memory Search tasks

Variable	*Raw* r	*Disattenuated* r
Median RT	+.914	+.998
RT intercept	+.832	+1.003
RT slope	+.503	+.653

B. Correlation (r) between Visual Search and Hick paradigm

Variable	*Raw* r	*Disattenuated* r
Median RT	+.478	+.526
RT intercept	+.571	+.728
RT slope	−.295	−.477

C. Correlation (r) between Memory Search and Hick paradigm

Variable	*Raw* r	*Disattenuated* r
Median RT	+.377	+.411
RT intercept	+.415	+.512
RT slope	−.149	−.276

D. Test–Retest Reliability, Spearman–Brown Boosted[a]

Task	*RT Median*	*RT Intercept*	*RT Slope*
Visual search	.908	.805	.690
Memory search	.924	.856	.859
Hick paradigm	.834	.765	.555

[a]These are the reliability coefficients used for disattenuating the raw correlations.

Correlations between Intercept and Slope

As was previously noted, there is an artifactual lowering of the correlation between intercept and slope when these parameters are calculated on the same data, due to a necessarily negative correlation between their errors of measurement. An illustration of this effect is consistently seen in Table 10, which shows the correlations between intercept and slope when these are calculated on the same data and on experimentally independent data. It is seen that the three paradigms differ significantly ($p < .01$) and even rather considerably in the degree of true correlation between RT intercept and RT slope.

Relationship of Chronometric Variables to Psychometric Intelligence

The Raven Advanced Progressive Matrices (APM) is a high-level nonverbal test of inductive and deductive reasoning ability based on abstract figures. It has been found to be highly loaded on Spearman's g factor (Paul, 1985). To ensure that the APM was taken as a power test and to minimize the speed factor, subjects were urged to take all the time they needed to solve every problem, and they were paid according to the total time they spent in taking the test.

Table 11 shows the correlations between APM scores and RT and MT variables obtained on each day and on the combined data of both days. Theoretically,

TABLE 10
Correlation between Intercept (*a*) and Slope (*b*) of RT for the Same Data and for Independent Data

	Same Data[a]		Independent Data[b]	
Paradigm	a_1b_1	a_2b_2	a_1b_2	a_2b_1
Visual Search	.294	.273	.408	.529
	(.494)[b]	(.459)	(.686)	(.888)
Memory Search	−.044	−.004	.075	.133
	(−.059)	(−.006)	(.099)	(.177)
Hick	−.640	−.661	−.314	−.148
	(−1.311)	(−1.354)	(−.643)	(−.303)

[a]Subscripts 1 and 2 refer to data obtained on Day 1 or Day 2.
[b]Disattenuated correlations are in parentheses.

all of the correlation coefficients should be negative, that is, high APM scores are expected to be associated with shorter RT and MT, smaller intraindividual variability (σ_i), and lower intercept and slope. These expectations were borne out, except for the slope parameter of the Hick paradigm and the nonsignificant positive r (+.045) for the combined days on the MT slope of VS. As has been found in many previous studies, the highest correlations are those for σ_i. The three chronometric paradigms scarcely differ in their correlations between APM scores and σ_i. The *intra*individual variability across trials measured by RTσ_i in elementary cognitive tasks (ECTs) seems to be a quite fundamental *inter*individual differences variable, perhaps even more basic than the mean or median RT or the intercept or slope of RT, with respect to the correlation between ECTs and psychometric g.

The largest and perhaps most surprising difference between VS and MS is on the RT slope parameter. It will be recalled from Tables 7 and 9 that the RT slopes of VS and MS are virtually identical, but the disattenuated correlation between these is +.65, hence, they reflect both common processes and unique processes. From Table 11, it appears that only the process reflected by RT slope that is unique to VS is significantly correlated with the APM. According to the theoretical model, this process is *stimulus encoding*. The process of *comparison*, the only process reflected in the slope of MS, is not correlated with the APM. Because intercept and slope are not experimentally or mathematically independent in the Day 1, Day 2, or combined data, we should look at the partial correlation between RT slope and APM, while holding the intercept constant. For VS, the disattenuated partial r is −.344 ($p < .05$); for MS, $r = -.050$ (n.s.). The MT slope correlations with APM for VS and MS seem to reflect a somewhat opposite relationship than is seen for RT slope, which suggests that, in MS, subjects may continue the process of stimulus comparison in the relatively

TABLE 11

Correlation[a] of RT and MT Variables with Scores on the Raven Advanced Progressive Matrices Test[b]

	Median			Intra-Variability (σ_i)			Intercept			Slope		
	Day 1	Day 2	Comb.[c]	Day 1	Day 2	Comb.[c]	Day 1	Day 2	Comb.[c]	Day 1	Day 2	Comb.[c]
RT Variable												
Visual Search	−315	−333	−339	−461	−357	−429	−147	−296	−246	−397	−195	−345
	(−379)	(−401)	(−390)	(−602)	(−467)	(−517)	(−196)	(−396)	(−301)	(−601)	(−295)	(−456)
Memory Search	−310	−266	−302	−380	−283	−370	−345	−232	−319	−006	−102	−055
	(−367)	(−315)	(−345)	(−526)	(−391)	(−462)	(−438)	(−295)	(−378)	(−007)	(−131)	(−065)
Hick paradigm	−009	−165	−092	−337	−341	−384	−082	−229	−173	+142	+170	+186
	(−010)	(−198)	(−106)	(−509)	(−515)	(−507)	(−115)	(−320)	(−217)	(+251)	(+301)	(+274)
MT Variable												
Visual Search	−167	−221	−221	−241	−249	−265	−109	−276	−218	−119	−175	+045
	(−259)	(−344)	(−298)	(−314)	(−325)	(−320)	(−170)	(−431)	(−295)	(−271)	(−399)	(+080)
Memory Search	−170	−271	−231	−259	−177	−238	−155	−157	−169	−091	−368	−285
	(−229)	(−365)	(−284)	(−322)	(−220)	(−279)	(−206)	(−209)	(−206)	(−176)	(−712)	(−449)
Hick paradigm	−203	−239	−231	−106	−101	−119	−204	−287	−268	+053	+275	+187
	(−244)	(−287)	(−265)	(−160)	(−153)	(−157)	(−267)	(−375)	(−324)	(−089)	(+461)	(+265)

[a]Correlations in parentheses are corrected for attenuation based on test–retest reliability and a reliability of .83 for the Raven APM. Decimals are omitted. Significance levels (for raw correlations) by one-tailed t test are $r \geq .242$, $p < .05$; $r \geq .337$, $p < .01$.

[b]Raven score: $M = 27.98$, $SD = 4.50$ ($N = 48$).

[c]Comb. = combined data of Days 1 and 2.

short MT interval between releasing the home button and pressing the *YES* or *NO* button.

Multiple Correlations. To get some idea of the maximum correlation that each main parameter (median, intercept, slope, σ_i) of this set of chronometric tasks has with the APM, multiple correlations were computed based on measurements from the VS, MS, and Hick paradigms as the independent variables and the APM as the dependent variable. So that all variables entering into a particular multiple correlation (R) would be experimentally independent, the median, intercept, slope, and σ_i parameters are analyzed separately, with an R computed for each of these parameters on the basis of six independent variables: RT and MT on the VS, MS, and Hick paradigms. The Rs based on these six predictor variables, with APM score as the predicted variable, for each of the four parameters are as follows (R based on disattenuated zero-order rs in parentheses): *Median,* .408 (.802), *Intercept,* .400 (.643), *Slope,* .496 (.918), *Intraindividual Variability* (σ_i), .504 (.566). Again, σ_i shows the largest overall correlation (uncorrected) between the ECTs and the APM, or psychometric g. (The Rs derived from the disattenuated correlations, however, show a quite different rank order of magnitude for the various parameters from the Rs derived from the uncorrected zero-order correlations, because of differences in the reliability of the four parameters and their differences in the degree of intercorrelation among the RT and MT variables of all three paradigms.) But the fact that these quite similar Rs (uncorrected) do not differ significantly indicates that each parameter of performance, when measured on six experimentally independent RT and MT variables, can yield highly similar multiple correlations with the APM. In view of the great restriction of range of ability in this university sample, which is selected from the top quarter of the distribution of IQ in the general population, these are quite remarkably high correlations, especially considering the apparently great difference between the task demands of the APM and of the three elementary cognitive tasks.

Factor Analysis. A more analytical view of the relationship of the APM to the ECTs is afforded by four separate Schmid–Leiman (1957) orthogonalized hierarchical factor analyses (originating with principal factors) of the APM along with each of the four sets (median, intercept, slope, and σ_i) of six variables each (RT and MT of VS, MS, and Hick). In brief, the same sets of variables from which the above multiple Rs were calculated were also subjected to factor analysis. The results are shown in Table 12. All of the variables within each factor analysis are experimentally independent measurements. (It would be a mistake to include in a factor analysis any two or more of these parameters derived from the same set of RT or MT measurements.)

The second-order factor is the general factor of the particular set of seven variables. The first-order factors are residualized, that is, their common variance

TABLE 12

Orthogonal Hierarchical Factor Analyses[a] of the Correlations between the Raven Advanced Progressive Matrices Test and the RT and MT Variables on Four Parameters of the Visual Search, Memory Search, and Hick Paradigm

	Median			Intercept			Intravariability (σ_i)				Slope			
		1st Order			1st Order			1st Order				1st Order		
Variable	2nd Order	1	2	2nd Order	1	2	2nd Order	1	2	3	2nd Order	1	2	3
Raven APM	−249	−146	−172	−263	−120	−164	−319	155	−183	−129	−281	057	483	−092
	(−273)	(−160)	(−189)	(−289)	(−132)	(−180)	(−350)	(170)	(−201)	(−142)	(−308)	(063)	(530)	(−101)
RT visual	593	−003	762	640	−049	741	843	−122	313	064	557	606	−461	−227
	(622)	(−003)	(800)	(713)	(−055)	(826)	(927)	(−134)	(344)	(070)	(671)	(730)	(−555)	(−273)
RT memory	484	−146	765	508	−103	651	898	−033	260	065	345	491	−051	−021
	(503)	(−152)	(796)	(549)	(−111)	(704)	(1000)	(−037)	(296)	(074)	(372)	(530)	(−055)	(−023)
MT visual	554	742	−033	602	557	094	929	280	035	024	057	−025	259	462
	(679)	(910)	(−040)	(740)	(685)	(116)	(1020)	(307)	(038)	(026)	(093)	(−041)	(422)	(753)
MT memory	553	667	039	642	698	−004	857	357	−035	−024	450	025	−259	600
	(620)	(747)	(044)	(714)	(776)	(−004)	(915)	(381)	(−037)	(−026)	(645)	(036)	(−371)	(860)
RT Hick	467	296	301	542	273	312	439	−152	103	739	−185	−057	337	092
	(490)	(310)	(316)	(619)	(312)	(357)	(528)	(−183)	(124)	(889)	(−248)	(−077)	(452)	(123)
MT Hick	458	591	−006	420	544	−089	472	−152	−103	644	168	515	512	247
	(480)	(620)	(−006)	(462)	(598)	(−098)	(569)	(−183)	(−124)	(776)	(217)	(665)	(661)	(319)
Percentage of variance	24.1	21.1	18.4	28.3	17.1	15.9	51.9	4.2	3.2	14.1	11.1	12.6	13.7	10.1
	(29.0)	(27.4)	(20.2)	(36.4)	(22.3)	(19.4)	(63.7)	(5.1)	(4.0)	(20.3)	(17.4)	(18.1)	(22.1)	(21.5)

[a]Decimals are omitted in factor loadings. Loadings in parentheses are corrected for attenuation.

has been removed to create the second-order factor, hence, all of the factors, between and within orders, are orthogonal, that is, uncorrelated.

The first point to note is that each of the parameters, with the exception of slope, has a substantial general factor, with substantial loadings of every one of the chronometric variables. The slope parameter does not display a true general factor, as some of the variables have near-zero or even negative loadings on the second-order factor. Probably the most important causes of this are that the slope parameter is really irrelevant to MT, which has little or no significant slope and, also, in these data, the slope of RT in the Hick paradigm is negatively correlated with the slope of RT in both the VS and MS paradigms, which fact alone would preclude the emergence of a true general factor. Moreover, the slope factors, both of the first and second orders, bear no resemblance to the factors on the other parameters, as indicated by congruence coefficients which fall below the value of .95 customarily required to claim factorial identity.

Second, it is noted that the general factor is essentially the same factor (that is, factor scores would rank-order individuals almost identically) for the median, intercept, and intraindividual variability (σ_i). The average congruence coefficient between them is .988 (regardless of whether the Raven APM is or is not included in the calculations). This indicates that for these six chronometric variables, a virtually identical general factor emerges whether one measures median RT and MT, or intercepts, or σ_i. This general factor is hard to describe in psychological or information-processing terms. It is not exactly a general speed factor, because σ_i is not a measure of speed per se, but of intertrial variability in RT and MT. The nature of the connection between speed and σ_i calls for further inquiry. It has been hypothesized elsewhere (Jensen, 1982, 1987) that individual differences in mean or median RT (or MT) are mainly a reflection of σ_i, which is actually the more basic phenomenon. Differences between median RT (or MT) and σ_i in factor structure at the level of the first-order factors, however, indicate that the median and the σ_i are not entirely isomorphic parameters of individual differences across a variety of ECTs.

On the first-order factors, the median, intercept, and σ_i part company to some extent. The congruence coefficient (r_c) on Factor 1 is very high between median and intercept (r_c = .989), but very low between median and σ_i (r_c = .510) and between intercept and σ_i (r_c = .491). However, Factor 1 can be labeled "MT" for all three parameters, although Hick MT is not positively loaded on this factor in the case of σ_i. Factor 2 is virtually identical (mean r_c = .973) for the median, intercept, and σ_i parameters and can be labeled "RT." It is noted that RT and MT part company only on the first-order factors, and both RT and MT have substantial and comparable loadings on the second-order, or general, factor. The fact that RT and MT so clearly part company on the first-order factors further highlights the theoretical justification for experimentally separating the measurement of RT and MT. It is most noteworthy that the two search paradigms, VS and MS, do not part company in the factor analyses, nor are they differentiated factorially from the Hick paradigm in any clear or consistent way.

Finally, we note the factor loadings of the Raven APM. The second-order factor loadings are all of similar magnitude (averaging −.278, disattenuated −.305) on the four parameters. Except in the case of slope, the APM has its major loading on the general factor, with the largest loading on σ_i. Quite consistent with many previous studies, the APM is more strongly correlated with RTσ_i than with any other parameter derived from various chronometric tasks, despite the often lower reliability of σ_i.

Probably the most important observation to be drawn from these factor analyses, however, is that Raven performance, or psychometric *g*, is predominantly correlated not with any one particular chronometric paradigm or parameter or variable or first-order factor, but with the hierarchical second-order factor common to all of these paradigms and parameters.

DISCUSSION AND CONCLUSIONS

The results are a mixture of good news and bad news. The good news is that these ECTs show highly significant correlations with a test of psychometric *g* and, hence, may serve as analytic tools for further exploring the nature of *g*. The bad news is that the data are at odds with the prevailing cognitive processing models of VS and MS. These models, therefore, seem a poor guide for theoretical formulations concerning any specific cognitive processes that presumably underlie psychometric *g*.

Is the failure to substantiate the predictions of the model peculiar to the data of the present study? To answer this question, we can compare the present results with those of three other studies that have used forms of VS and MS that procedurally are fairly comparable to the present study. These comparisons are summarized in Table 13. In the model, *a* is the amount of time required for *binary* decision and *response production*, *b* is the time for *a single comparison*, and *x* is the time for *stimulus encoding*. The order contrasts in Table 13 tell the whole story. For intercepts, only one study (Ananda, 1985) out of the four agrees with the model, but the difference between the VS and MS intercepts is nonsignificant ($p > .05$). For slopes, two studies (Jensen and Ananda) agree with the model, but nonsignificantly. The *N*-weighted means of the combined studies go *opposite* to the model for both intercept and slope. Sternberg's model of the processing stages of the MS paradigm, at least, is an *additive* factors model, that is, the times required for the various processes (stimulus encoding, comparison, binary decision, and response production) are additive, and Sternberg (1969) argues this point convincingly in terms of experimental data. But Sternberg has offered no model of the VS paradigm, and it is in this model, proposed by Chiang and Atkinson (1976), that the trouble may lie. The processing demands of VS may not be a simple reversal of the processing demands of MS, even though the experimental arrangement of the two paradigms is merely reversed. But this is a problem for experimental cognitive psychology. Of primary interest in the present study is the relationship of the ECTs to psychometric *g*.

TABLE 13

Mean Intercept and Slope Parameters (in ms) of the Visual Search and Memory Search Paradigms in Four Independent Studies Compared with the Order Contrasts Predicted by the Theoretical Models of These Paradigms

Study[b]	N	Visual Search (VS)			Memory Search (MS)			Order Contrasts[a]	
		Intercept	Slope	Fit (r)[c]	Intercept	Slope	Fit (r)	Intercept	Slope
Model		a	$b+x$		$a+x$	b		*VS<MS*	*VS>MS*
Jensen (1987)	48	467	25	.919	429	24	.991	VS>MS	VS>MS (n.s.)
Chiang & Atkinson (1976)	34	445	40	.972	429	44	.998	VS>MS	VS<MS
Ananda (1985)	76	567	50	.845	569	45	.980	VS<MS (n.s.)	VS>MS (n.s.)
Wade (1984)	60	501	13	.855	420	35	.991	VS>MS	VS<MS
N-Weighted Mean	218	508	33	.898	475	37	.991	VS>MS	VS<MS

[a]Differences between VS and MS that are in accord with the theoretical model but are statistically nonsignificant at α .05 (two-tailed) are marked n.s. Significant differences in accord with the model are marked with an asterisk. (There is none.)

[b]Set sizes were: Wade, 1–4; Chiang & Atkinson, 1–5; both Jensen and Ananda, 1–7. Letters were used by Chiang & Atkinson; digits were used by all the others.

[c]The degree to which the mean RT data points fit the *linear* regression of RT on set size is indicated by the Pearson r between mean RT and set size.

Psychometric *g*, as measured by the Raven Advanced Progressive Matrices (APM), was significantly correlated with each of the paradigms (VS, MS, Hick). VS and MS show generally larger correlations with the APM than does the Hick. RT shows larger correlations with APM than does MT. For both RT and MT, intraindividual variability, σ_i, shows larger correlations with APM than either the median, intercept, or slope parameters. Multiple correlations between the chronometric variables of the various paradigms and APM are about .50, which is quite substantial, considering the lack of intellectual content in these exceedingly simple chronometric tasks and the high level and severely restricted range of intelligence in this sample of university students. The correlations between the various RT parameters and psychometric *g* in this study are generally similar to the correlations found in other studies conducted with apparatus and procedures that are highly similar to those of the present study. The one exception is the study by Chiang and Atkinson (1976), which was considerably different in apparatus and procedures; for example, it did not measure RT and MT sepa-

TABLE 14
Correlations of Various Psychometric Tests with RT Parameters of Memory Search, Visual Search, and Hick Paradigms in Several Studies

	Study				
Variable	**Ananda**	**Chiang & Atkinson**	**Jensen**	**Vernon**	**Wade**
N	**76**	**30**	**48**	**100**	**60**
Sample	Elderly	Univ. Stud.	Univ. Stud.	Univ. Stud.	Gifted Chil.
Psychometric test	Raven SPM[2]	SAT: V&M[3]	Raven APM[4]	WAIS–FSIQ[5]	Raven SPM[2] + APM[4]
Set size of display	1–7	1–5	1–7	1–7	1–4
	Correlation				
Memory Search					
RT Median or Mean	−.161		−.302	−.310	−.397
RT Intercept		.202 (−.389)[3]	−.319		
RT Slope		.194 (.029)	−.055		
RT σ_i	−.192		−.370	−.307	−.245
Visual Search					
RT Median or Mean	−.210		−.339		−.249
RT Intercept		.140 (.287)	−.246		
RT Slope		.345 (−.048)	−.345		
RT σ_i	−.185		−.429		−.254
Hick					
RT Median or Mean	−.450		−.092	−.247	−.073
RT Intercept			−.173	−.167	
RT Slope			−.186	−.224	
RT σ_i	−.229		−.384	−.320	.121

[1]Correlations from Vernon (1981).
[2]Standard Progressive Matrices.
[3]Scholastic Aptitude Test (Verbal and Mathematical); correlations for M are in parentheses.
[4]Advanced Progressive Matrices.
[5]Wechsler Adult Intelligence Scale–Full Scale IQ.

rately. Correlations reported in several studies are compared with those presented here in Table 14.

Hierarchical factor analysis reveals that it is the second-order, or general, factor common to the median, intercept, and σ_i parameters of both RT and MT variables on all three paradigms (VS, MS, Hick) that is mainly correlated with the APM, or psychometric *g*, rather than any specific parameters, variables, or paradigms. Although the slope parameter shows some fully significant correlations with APM, it is peculiarly inconsistent across paradigms and variables, and slope yields no truly general factor among these paradigms. Factorially, slope is by far the most problematic parameter.

The general factor common to the median, intercept, and intraindividual variability (σ_i) of both RT and MT in the VS, MS, and Hick paradigms, and on which the APM has its predominant loading, cannot be adequately described as general speed of information processing because of the prominent role of σ_i in this factor. It might be characterized psychologically as something like "attentional resources," but such vague terms are not theoretically very suggestive of empirically testable explanatory mechanisms. Perhaps intraindividual differences in response latency (median or intercept of RT and MT) and in σ_i are both related to some more basic process that will have to be understood in neurophysiological rather than psychological terms.

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APPENDIX A

Day 1 × Day 2 Correlations of Variables

	Day 1 × Day 2 Correlation				Spearman–Brown Boosted			
	RT		MT		RT		MT	
Variables	Visual	Memory	Visual	Memory	Visual	Memory	Visual	Memory
Median: SS 1	.741	.709	.453	.723	.8512	.8297	.6235	.8392
SS 2	.741	.778	.473	.619	.8512	.8751	.6422	.7646
SS 3	.814	.845	.472	.607	.8974	.9159	.6413	.7554
SS 4	.733	.821	.518	.600	.8459	.9017	.6824	.7500
SS 5	.812	.789	.480	.685	.8962	.8820	.6486	.8130
SS 6	.844	.817	.506	.592	.9154	.8992	.6719	.7437
SS 7	.747	.845	.389	.571	.8551	.9159	.5601	.7269
Mean Median	.832	.858	.498	.662	.9082	.9235	.6648	.7966
Intercept	.673	.748	.494	.679	.8045	.8558	.6613	.8080
Slope	.527	.754	.232	.321	.6902	.8597	.3766	.4859
σ_i: SS 1	.365	.158	.548	.361	.5347	.2728	.7080	.5304
SS 2	.357	.429	.481	.585	.5261	.6004	.6495	.7381
SS 3	.245	.309	.320	.427	.3935	.4721	.4848	.5984
SS 4	.484	.399	.523	.705	.6522	.5704	.6868	.8269
SS 5	.414	.490	.653	.743	.5855	.6577	.7900	.8525
SS 6	.406	535	.668	.753	.5775	.6970	.8009	.8590
SS 7	.546	.551	.664	.717	.7063	.7105	.7980	.8351
Mean σ_i	.705	.629	.709	.782	.8269	.7722	.8297	.8776