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Assessment of Basic Cognitive Abilities in Relation to Cognitive Deficits

Douglas K. Deltaman, John D. Mayer, David R. Carnos, Peter J. Legree, Frances A. Conners, and
Rolf Taylor
Case Western Reserve University

A model of information-processing was used to select a battery of nine tasks of basic cognitive ability (learning, relearning, reaction time, probe recall, Sternberg search, self-paced probe, stimulus discrimination, tachistoscopic fall report, tachistoscopic partial report). Parameters from these tasks operationalized the model. After extensive pilot testing of the tasks to establish reliability, we tested 40 subjects (20 with mental retardation and 20 college students) on all tasks and the WAIS-R. The parameters from the tasks were generally reliable (.7 through .9) and had low correlations with IQ (average about .37). Nearly all of the major cognitive parameters differentiated significantly between groups. A subset of the basic cognitive parameters predicted IQ with an estimated multiple correlation in the general population of .72. Prediction of IQ using basic cognitive parameters was better for subjects with mental retardation than for college students. A modified version of the model model was supported. Results show that individual differences in higher mental processes are highly dependent on basic cognitive abilities and can be predicted from them. These findings have substantial implications for the development of models of information-processing.

Many contemporary researchers share the opinion of Sternberg and Salter (1982) and Keating (1983) that measures of cognitive processes will never be capable of

Portions of this work were supported by Grants No. HD07176 and HD15516 from the National Institute of Child Health and Human Development, Office of Mental Retardation, the Air Force Office of Scientific Research, and the Brooks Air Force Base Human Resources Laboratory. Project Lamp. Requests for reprints should be sent to Douglas K. Deltaman, Department of Psychology, Case Western Reserve University, Cleveland, OH 44106.

accounting for differences in intellectual functioning. Still, it is important to know whether measures of basic processes show reliable individual differences. If they do not (Underwood, 1975), they cannot provide useful information about general cognitive functioning. Galton (1883) and Cattell (1890) noted that measures of basic mental abilities such as memory and perception should predict general intellectual functioning. Testing this hypothesis is difficult methodologically (Tuddenham, 1963). In addition to not confirming the relation between basic cognitive functions and intelligence, early studies made

if unfunctional to study individual differences. However, some recent research suggests that simple measures of reaction time—RT (Detemman, 1987a; Jensen, 1979; Jensen & Munro, 1979; Jensen, Schaefer, & Crinella, 1981), memory (Butterfield, Wambold, & Belmont, 1973; Ellis, 1970), and perception (Nettelbeck, 1982, 1985) do correlate slightly to moderately with mental age (MA) and IQ. If these measures tap separate cognitive processes, then combining them may reveal much higher multiple correlations with intelligence test scores. The research reported in the present paper is a preliminary test of this possibility.

First, a modal model of cognitive functioning was defined. Next, nine tasks were developed to operationalize each part of the model. These tasks were tested extensively to ensure that they could be completed by persons with mental retardation and that they yielded reliable measures. Finally, all of the tasks and the Wechsler Adult Intelligence Scale-Revised—WAIS-R (Wechsler, 1981) were administered to young adults with mental retardation and to college students

who were approximately the same chronological age (CA).

The Model

Figure 1 shows the modal model adopted. It consists of four memory stores—very short-term, primary, secondary, and tertiary—all of which are served by a stimulus encoding mechanism for input and a retrieval mechanism for output. An executive mechanism oversees the movement of information through the system. Rehearsal is one mechanism under control of the executive.

The four memories differ in how much and how long they store information and in the mechanism of forgetting. Very short-term memory holds unlimited sensory information for under a second, and forgetting results from overwriting subsequent incoming information. Primary memory holds little information for a few seconds, and forgetting occurs by replacement unless information is rehearsed. If rehearsed sufficiently, material moves from primary memory to

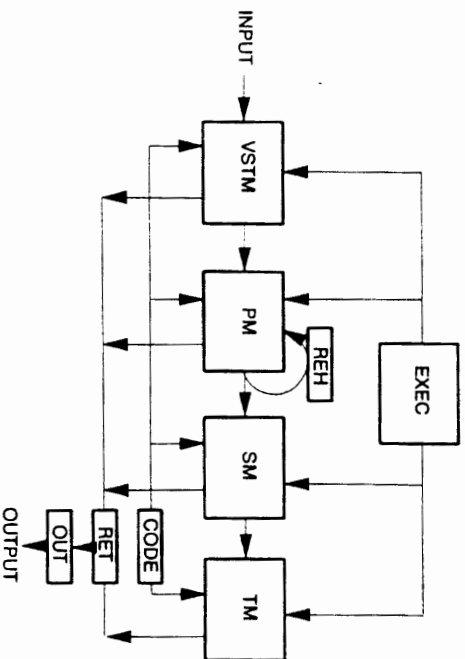


Figure 1. A modal model derived from studies of individual differences in information processing for subjects of different levels of intelligence. See Table 2 for explanations of abbreviations.

secondary memory. Secondary memory retains large amounts of information from minutes to days, and forgetting is probably due to interference. Very well-learned information (e.g., one's name, language) is stored in tertiary memory and may never be forgotten. Very short-term memory is called "a nearly process" and tertiary memory, "a late process" because information enters the system through very short-term memory and works its way successively to tertiary memory.

Table 1 lists the main measures derived from the nine basic cognitive tests used to operationalize parts of the modal model. Many investigators conducting experimental work with people who have mental retardation have used these tasks singly, but no one has combined them in a single study. As can be seen in Table 1, each task is assigned a code, which is the first two letters of each measure's code. Each task yields many different performance measures. Only the main measures used in this study are listed in Table 1. Also, we point out that not everyone would agree with the operationalization of this model. Many of the terms are not clearly operationalized by a single measure. There are two reasons for this: (a) theoretical terms are often ambiguous and (b) experimental measures are often not pure measures of a single process.

Table 2 shows how we assigned measures in Table 1 to parts of our modal model. Our assignments can be debated, but, for the most part, they reflect prior use of the measures (see review by Detemman, 1979), and, regardless, the assignments are tentative. The easiest to interpret outcome from this research would be that measures of one or a few processes discriminate subjects with mental retardation from those without mental retardation, with measures of other processes showing no difference. This would support a parsimonious specific deficit theory of mental retardation. However, because all of the measures taken separately have discriminated between people with and without mental retardation (see Detemman, 1987a), a more complex pattern is likely. A more

Table 1
Description of Measures From Nine Tasks

Task code/Measure	Measure code
Learning (LR)	LRTOTAL
No. of trials	LRTIME
Median correct RT* response	LRBIAS
Chi-square measure of bias	
Relearning (RL)	RLTOTAL
No. of trials	RLTIME
Median RT, correct positions	RLBIAS
Chi-square measure of position bias	
Reaction time (RT)	RT-MEAN
Mean decision time, all trials	
Y-intercept of decision time over set time	RTYINT
Slope of decision time over set time	RTSLOPE
SD of decision time	RTSD
No. of errors across all trials	RTERRORS
Probed Recall (PR)	PRERROR
No. of errors	
Chi-square bias measure for position bias	PRBIAS
Errors at Serial Positions 1 and 2	PRSM
Errors at Serial Positions 5 and 6	PRPM
Sternberg Search Task (ST)	
Mean decision time, positive trials	STDPM
Slope of decision time by set size, positive trials	STDPS
Y-inter, of decision time by set, positive trials	STDPI
Y-inter, of decision time by set, negative trials	STDAI
% errors, positive trials	STEP
% errors, negative trials	STEA
Self-Paced Probe Task (SP)	
No. of errors	SPERROR
Mean RT to answer each item	SPDANS
Mean study time for each item	SPDALL
SD of study time	SPSDALL
Stimulus Discrimination (SD)	
Mean decision time	SDDT
Mean movement time	SDMT
No. of errors	SDERROR
Tachistoscopic Full Report (TF)	
Mean threshold of exposure time	TFMEAN
Median threshold of exposure time	TFMED
Tachistoscopic Partial Report (TP)	
Overall proportion correct	TPPROP
Reaction time	

complex pattern of results would require a more intricate conceptualization of intelligence (e.g., Detemman, 1987a).

Method and Results by Task

Subjects

Subjects were 20 students with mental retardation from special education classes in

Table 2
Assignment of Measures to Part of Modal Model

Part of model	Measure code*	Measure
Very short-term memory (VSTM)	Capacity	TOPROP (9)
	Decay rate	TIMEAN (15)
	Primary memory (PM)	TIMEED (17)
	Capacity	PERERR (4)
Retrieval rehearsal (REH)	Retrieval rehearsal (REH)	PPPM (7)
		SPDIANS (12)
		SPDIAL (25)
Secondary memory (SM)	Capacity	SPSDALL (29)
	Retrieval	PRSM (5)
Tertiary memory (TM)	Acquisition	LRTIME (27)
	Retention	LRTFAL (2)
	Retrieval	LRTRAL (3)
		LRTIME (28)
	Executive functioning (EXEC)	SPERROR (1)
Stimulus Coding (CODE)	LABIAS (19)	No. of errors
	RUBIAS (23)	Chi-square bias in learning
	PBBIAS (6)	Chi-square bias in probed memory
	STEP (13)	Error rate, positive set trials
	STEA (11)	Error rate, negative set trials
	SDDT (10)	Mean decision time for stimulus discrimination
Retrieval (RET)	SDERROR (8)	No. of errors
	STDPM (14)	Mean decision time, positive trials
Peripheral	STDP (22)	Slope decision time, by set size, pos. trials
	STDI (16)	Y intercept, decision time by set size, pos. Y intercept, decision time by set size, neg.
Output (OUT)	SDM (24)	Mean movement time
	RTMEAN (21)	Mean decision time in reaction time
Efficiency (EFF)	RTYINT (20)	Y intercept of correct responses
	RTSLOPE (31)	Slope of decision time by bits of information
	RTSD (26)	SD of decision time, correct response
	RTERRORS (30)	No. of errors

*Numbers in parentheses are rank order of the standardized magnitude of differences between groups.

a middle-class suburb (mean WAIS Full-Scale IQ = 67.45, standard deviation [SD] = 7.56, range = 49 to 80), and 20 college student volunteers (mean WAIS IQ = 115.55, SD = 7.79, range = 94 to 132) from introductory psychology classes. Although each group had a curtailed IQ range, the combined group had an extended range ($SD = 25.51$), a natural result of our extreme group design. Although it would be desirable to be able to determine the independent contribution of IQ and MA to differences in cognitive ability

reflected in the basic cognitive tests, this was not possible because of the restricted age range. The mean age of the subjects with mental retardation was 18.25 years ($SD = 1.65$) and of college subjects, 18.95 years ($SD = 1.28$). Using raw score on the WAIS-R as an index of MA, we found that the correlation between Full-Scale WAIS-R and MA was .995. This high correlation indicates that IQ and MA provide almost exactly the same information in this sample. In the following discussion, one should remember that IQ and MA

could not be distinguished in this sample.

Procedure

All subjects were tested with the nine basic cognitive tasks and the WAIS-R. Testing took place in small (1.5 m) testing rooms, and took 3.5 to 5 hours, distributed over two sessions one day apart. When they arrived at the lab, subjects were shown to the testing cubicle and were given general instructions concerning the tasks. All further instructions and all cognitive testing were administered by computer. However, for students from special education classes, there was an experimenter present to maximize motivation and cooperation. All instructions included practice trials, which, in most cases, did not use stimuli included on the test trials. The experimenter answered any questions and transferred data to diskettes after each task was completed. Subjects were allowed to rest between tasks and at the midpoint of each task if they wished.

The WAIS-R was administered by a trained graduate student. All answer sheets were checked by another student, and a third person rechecked the answer sheets. The lowest scoring college student showed an unusual pattern of WAIS subtest scores, but his Full-Scale IQ was used because the experimenter thought the questionable subtests were valid.

All of the cognitive tasks were administered by a Terak 8510a computer fitted with touch screen voice synthesizer (Votrak Type-n-Talk) and frequently calibrated video monitors. The touch screen allowed all responses to be made by touching the video monitor positioned at eye level. Most tasks began with the subject pressing a "bar" or home key, at the bottom of the monitor. Subjects never touched the keyboard during testing.

All subjects were instructed to use the index finger of their preferred hand. They were allowed to switch fingers or hands, but all subjects were carefully watched to ensure that they used only one finger on one hand

at a time. When subjects attempted to use two hands, they were warned to use only one. In one case, the experimenter held one of a subject's hands.

For all tasks, a correct response was signalled by a beep and an incorrect response by a click. Some of the tasks provided additional feedback through the voice synthesizer, which was used to present all instructions and prompts during testing. The voice synthesizer's "computer" accent was understandable, and an experimenter was available to answer questions. Timing to an accuracy of about 17 msec was accomplished by the TIME function of U.C.S.D. Pascal.

Stimuli

Stimuli for tasks were twenty-four 2 cm x 2 cm, 4 x 4 matrices with some cells filled (cf. Canoso & Detterman, 1983a, 1983b). The number of cells filled fit the random expected distribution. All subjects received the same random orders of stimuli, and the tasks were administered in the same order. Typical psychometric practices of arranging items by difficulty or selecting discriminating items were not used.

Pilot Testing

Tasks used were pilot tested with hundreds of subjects to produce reliable measures. We found that most tasks, although quite adequate for demonstrating differences across experimental conditions, did not yield reliable individual differences measures until they were altered substantially.

Split-half reliabilities are reported. IQs are WAIS-R Full Scale. All times are reported in milliseconds unless otherwise indicated.

LEARNING (LR)

LR was designed to measure learning of an association between a stimulus and its position in an array, which should reflect later processes in the modal model, such as

terinary memory. DeJteman (1979) has noted that later stages of information-processing may be confounded by deficits in earlier stages. Therefore, learning may not be a clear measure of these later processes but may also reflect deficits earlier in the system.

Although people with mental retardation have been found to have deficits in learning, the relation between learning and IQ often has been said to be rather low, perhaps accounting only for 20% of the variance of intelligence (Crocker, 1974). Evidence from the literature on persons with brain damage and idiots savants shows that memory can be unusually good when intelligence is low (DeJteman, 1979).

Method

Task

LR was a fixed list, multitrial learning procedure. Eight blank stimulus squares appeared evenly spaced horizontally across the screen, with a ninth empty stimulus square centered 1 cm above the eight-square array. The eight stimuli to be learned appeared for one second, one after the other in the horizontal eight-stimulus array, with no interstimulus interval.

Immediately after the eighth stimulus was presented, one of the eight stimuli appeared in the top "probe" position. The participant's task was to touch the square in which the probe stimulus had appeared. An auditory stimulus was sounded when a square was touched, and the correct position flashed for 1.0 seconds. Then, a second stimulus was presented in the probe window, and so on, until all eight stimuli had been tested. This procedure was repeated until a criterion of one perfect trial or 40 trials was reached.

Results

Missing Data. Two persons' data, one from each group, were missing from the LR

task due to experimenter error. For both cases, the mean within-group values were assigned for each LR measure.

Measures

Most of the variables recorded from this task estimated speed of learning; three additional parameters were derived that quantified individual differences in response bias and response speed. *LRTRIAL*: The simplest measure for LR was the number of trials to one perfect recall of the eight stimuli or 40 trials, whichever came first. Thus, the measure could range from 1 to 40. *LRADJTRIAL*: For subjects who reached trial 40, an adjusted trials score was calculated: $LRADJTRIAL = 40$ divided by the overall percentage correct on the last 3 trials. For example, if *LRTRIAL* was 40, and the participant averaged 50% over the last 3 trials, then *LRADJTRIAL* would be 80. For participants with *LRTRIAL* less than 40, *LRADJTRIAL* = *LRTRIAL*. *LRPERCORR*: Percentage correct was calculated from the number of correctly responded to probes. We assumed that subjects who learned the stimuli in less than 40 trials would have continued to perform perfectly on the remaining trials. Thus, $LRPERCORR = (\text{number probes correct} + \text{assumed correct}) / 320$ (40 trials \times 80 positions). *LRMARKOVP* and *LRMARKOVA*: Viewing LR as a two-state Markov process in which a subject's knowledge of a stimulus may change on a given trial from either learned to unlearned with probability *P*, or from unlearned to learned with probability *A*, we calculated the probabilities *P* and *A* for each pair of successive trials, and trial (T) and T-1 for each item, which we averaged separately across all trial pairs, yielding *LRMARKOVP* and *LRMARKOVA*. If a subject was perfectly correct on Trial 1, then *LRMARKOVP* was 0.0 and *LRMARKOVA* was 1.0. *LRPRIMACY* was percentage correct at Positions 1 and 2 minus percentage correct at Positions 4 and 5. *LRRECIENCY* was percentage correct in Positions 7 and 8 minus percentage correct at Positions 4 and 5. Both

measures could range from -1 to 1. *LRVAMEDC* was median response time of correct responses. *LRBIAS*: Chi-square was calculated for the number of observed responses at each position against an expected distribution of equal numbers of responses for each position. *LRBIAS* was scored 1 if a participant's chi-square was significant, 0, if not significant. *LRNULLRESP*: The number of no responses within 8 seconds of probe presentation plus responses to an inappropriate place were summed to measure task inappropriately responding.

Descriptive Statistics

The mean and *SD* for each measure for each group are shown in Table 3. Distributions of some measures departed from normality: *LRBIAS* and *LRNULLRESP* showed behaviors that were virtually nonexistent among the participants who did not have mental retardation, but substantially present among those who did. *LRMARKOVP*, *LRMARKOVA*, *LRPERCORR*, and *LRVAMEDC* were distributed normally for both groups.

Reliabilities and Correlations

Reliabilities of most measures could not be calculated because the task could not be split into two independent halves. Correlations across groups were high. The three highest correlations with IQ were *LRTRIAL*, *r*

$= .85, p < .001$, *LRPERCORR*, $r = .80, p < .001$, and *LRMARKOVA*, $r = .76, p < .001$, all of which quantify learning. The high correlations for participants with mental retardation may be due to their greater variability on these measures. (See Table 3).

Prediction of WAIS-R IQ from this task seemed poor for the college student group, good for the retarded group, and excellent for prediction across groups. The results seem to contradict findings that learning has only a low relation to IQ. Especially incompatible with this view is the $-.85$ correlation between trials-to-criterion and WAIS-R IQ.

RELEARNING (RL)

Task RL used the same stimuli and procedure as task LR and was used to measure savings in relearning the day after LR was given. It measures long-term memory, which has been related often to IQ. Conclusions concerning long-term memory are similar to those for learning. For instance, Belmont (1966) suggested that long-term retention is not influenced by intelligence and, in fact, that it is equal for people with and without mental retardation.

Method

Task

The relearning task was presented 24

Table 3 Means, SDs, Reliabilities, and Correlations With WAIS-IQ of Measures From Learning (LR)

Variable	College students		Mentally retarded		Combined groups		Reliability	r_{IQ}
	Mean	SD	Mean	SD	Mean	SD		
LRTRIAL	8.69	5.25	34.53	10.77	21.61	15.53	.85	-.85
LRADJTRIAL	8.68	5.25	233.36	299.67	121.02	238.1	-.53	-.80
LRPERCORR	.62	.09	.32	.17	.47	.21	.80	.80
LRMARKOVP	.30	.13	.56	.13	.43	.19	.83	-.71
LRMARKOVA	.67	.11	.34	.21	.51	.23	.83	.76
LRPRIMACY	.002	.192	.033	.062	.017	.142	.06	.06
LRRECIENCY	.058	.167	.025	.051	.012	.123	.96	-.13
LRTIME (sec)	7.81	4.33	5.27	4.06	6.54	4.33	.84	.36
LRBIAS	6.00	6.91	53.75	68.23	29.88	53.63	.84	-.56
LRNULLRESP	7.37	1.02	14.42	24.27	7.58	18.31	.99	-.41

*Correlation of the variable with IQ.

hours after the learning task. Instructions, procedures, and parameters were identical to the learning task in all but two respects. First, the task began by probing the eight positions that had been learned the day before rather than first presenting the stimuli. Second, the task was shortened so that subjects received a maximum of 25 trials.

Results

Measures

Measures were identical to those for the learning task, with two slight changes and one addition. *RLSAVE*: Savings on the relearning task compared to the learning task was calculated as $RLTRIAL$ for the learning task divided by $RLTRIAL$. This is the classical measure of savings (Woodworth, 1938). $RLTRIAL$ and $RLADJTRIAL$ were changed to allow for the use of 25 rather than 40 trials.

Descriptive Statistics

Means and *SDs* for each *RL* measure can be seen in Table 4. Of particular interest is the fact that both groups displayed almost exactly the same amount of savings on relearning. Evidently, long-term retention of learned

material does not differ with ability, as Belmont (1966) concluded.

Reliabilities and Correlations

Reliabilities could not be calculated for most *RL* measures but, where they could be calculated, were moderate to high (.56 to .87). Correlations with *WAIS IQ* for college students were similar to those for LR, with one exception. *RLPERCORR* correlated with *WAIS IQ*, $r = .50$, $p < .01$. No other correlations were significant. Correlations with *WAIS IQ* were considerably higher for participants with mental retardation. The three high correlations were *RLBIA*, $r = -.76$, $p < .001$, *RLMARKOVA*, $r = .72$, $p < .001$, and *RLPERCORR*, $r = .68$, $p < .001$, none of which reflect relearning. As for LR, lower correlations for college students may reflect their lower reliability on the *RL* measures. Correlations across groups were high, ranging up to *RLTRIAL*, $r = .84$, $p < .001$, *RLMARKOVA*, $r = .72$, $p < .001$, *RLPERCORR*, $r = .68$, $p < .001$, and *RLBIAS*, $r = -.55$, $p < .001$. *RLSAVE* did not correlate with *IQ*. Relearning measures added very little to learning measures.

CHOICE REACTION TIME (RT)

Individuals with mental retardation and college students differ in their RTs. College students are typically faster and more consis-

tent in both simple RT (Baumeister, Hawkins, & Kellas, 1965; Baumeister & Kellas, 1968a, 1968b; Baumeister, Urquhart, Beedle, & Smith, 1964; Berkson & Baumeister, 1967) and choice RT (Lally & Nettelbeck, 1977; Nettelbeck & Brewer, 1976; Wade, Newell, & Wallace, 1978). Relations have been found between *IQ* and choice regardless of the number of choices (Jensen, 1979; Lally & Nettelbeck, 1977; Vernon, 1981, 1987).

Method

Modeled after Jensen's (1979) choice RT task, the RT task in the present study required that subjects respond to the onset of one of up to eight possible stimuli. Reaction time differed from Jensen's procedure in that (a) the number of possible stimuli changed randomly from trial to trial rather than being blocked and (b) when there were one, two, or four possible stimuli, their screen positions changed from trial to trial, instead of maintaining constant screen positions.

Stimuli and Task

Stimuli were completely empty and completely filled matrices, which appear as lit or unlit squares. Eight matrix positions were arranged on the screen along a semi-circle, each equidistant from the home key at the bottom of the screen. Either one, two, four, or eight matrices might be displayed on a given trial.

A trial started when a participant touched a home key, which they were required to touch until responding. If they lifted their fingers before it was time to respond, a buzz reminded them to keep their fingers in place, and the trial was started over. When the home key was touched, it lit up, a warning tone was sounded, and a set of one, two, four, or eight empty matrices appeared on the screen. After a random interval of from 2 to 4 seconds, one of the displayed matrices was lit, and the participant was expected to touch that matrix as quickly as possible. After

a response, the display disappeared and the subject could start the next trial at any time by touching the home key.

There were 96 trials after 10 practice trials in RT. Each of the four display sizes (one, two, four, eight) was presented 24 times. The lit square appeared in each of the eight possible positions three times for each display size. Distractor positions for Display Sizes 2 and 4 were determined randomly. The 96 trials were presented in a simple random order for all subjects. Thus, display size was not blocked, as is done in much RT research.

Procedure

To begin, a demonstration trial and 10 practice trials were given. All practice trials presented eight choices. During the 96 experimental trials, subjects were verbally reinforced by the computer if the decision time on that trial was faster than their previous fastest decision time or faster than that of all of the preceding 5 trials. The reinforcers given were randomly drawn from a pool of five possible reinforcers, such as "fastest so far," "faster than a speeding bullet," and "best one yet."

Data recorded for RT included decision time (from the time one matrix lit up until the time the subject lifted his or her finger to respond), movement time (the time from lifting his or her finger until touching the lit matrix), and errors (touching an incorrect matrix or missing all matrices).

Results

Parameters

Five measures were calculated from each participant's correct trials only. *RTMEAN* was the mean decision time computed from the decision times of all (non-error) trials, regardless of display size. *RTSD* was *SD* of decision time computed from all trials.

Table 4
Means, *SDs*, Reliabilities, and Correlations with *WAIS-III* of Parameters From Relearning (*RL*)

Variable	College students		Mentally retarded		Combined groups		Reliability	r_s
	Mean	<i>SD</i>	Mean	<i>SD</i>	Mean	<i>SD</i>		
<i>RLTRIAL</i>	3.60	2.52	19.05	7.65	11.33	8.05		-.84
<i>RLADJTRIAL</i>	3.60	2.52	51.92	46.69	27.76	40.79		-.67
<i>RLPERCORR</i>	.80	.09	.46	.23	.63	.24		.79
<i>RLMARKOVA</i>	.09	.10	.48	.19	.28	.25		-.82
<i>RLMARKOVA</i>	.87	.15	.48	.25	.68	.28		.76
<i>RLPERCORR</i>	-.08	.19	-.03	.14	-.05	.17		-.17
<i>RLBIAS</i>	.07	.18	.05	.15	.06	.16		-.09
<i>RLTIME*</i>	9.62	5.37	6.69	5.29	8.15	5.46		.29
<i>RLBIAS</i>	1.93	1.27	32.71	47.62	17.32	36.72		-.55
<i>RLNULLRESP</i>	.55	.69	2.00	4.10	1.28	3.00		-.26
<i>RLSAVE</i>	1.53	.41	1.57	.15	1.55	.31		-.09

*In seconds.

RT/SLOPE was the slope of mean decision time across log (base 2) of display size. *RT/INT* was the intercept of *RT/SLOPE*. *RT/ERRORS* was percentage of trials with errors.

Descriptive Statistics

Means and SDs for the groups separately and combined are shown in Table 5. As expected, participants with mental retardation responded slower than did college students and were more variable within- and between-subjects. Although decision time intercepts also followed the expected pattern, slopes were virtually flat, perhaps because of unreliability.

Reliabilities and Correlations

RT/INT was reliable (.90) and correlated strongly with IQ (-.52). *RT/MEAN* was reliable only for college students (.78), but correlated significantly with IQ anyway (-.43). More intelligent participants had lower intercepts and lower mean decision times than did less intelligent subjects. *RT/SLOPE* and *RT/SD* did not correlate significantly with IQ, presumably because of attenuation caused by low

reliabilities, and correcting for attenuation, the correlations were .54 (*RT/SLOPE*) and -.87 (*RT/SD*). These differences in reliability suggest that as IQ increases, the effect of display size on decision time and its variability decreases. Blocking display size across trials might increase reliability.

PROBED RECALL (PR)

Short-term memory has been found to be deficient in individuals with mental retardation (Detteman, 1979) and related to intelligence in a sample of persons without mental retardation (Cohen & Sandberg, 1977, 1980). The short-term memory task employed in this study may be considered solely a measure of primary memory or of both primary and secondary memory, depending upon the specific operational definition of primary memory one selects. For our purposes, the task may be viewed as a measure of both primary memory and secondary memory, if data are analyzed for the last two and first two serial positions, respectively. Typically, primary memory is viewed as being relatively intact in persons with mental retardation, with the memory deficit being focused in secondary memory (e.g., Ellis, 1970). In several studies, however, investiga-

tors have found evidence for a primary memory deficit (Cohen & Sandberg, 1977, 1980; Detteman & Ellis, 1970).

Method

Task

The task we used to assess short-term memory was a six-position probed recall task similar to that employed by Ellis (1970). When a home key was touched, a beep sounded and a stimulus display appeared. If the home key was still being touched, one of the 24 possible stimuli appeared in the first open window for 1 second. The position displaying the stimulus then went blank, and the stimulus in the next position appeared for 1 second, and so on for six positions. Next, one of the six presented stimuli appeared in the position above the row. The subject tried to recall and touch the position that this stimulus had appeared in. If he did, the speech synthesizer responded "yes"; if not, a click was presented. Then the entire screen was cleared. The speech synthesizer then said, "Next," indicating that there was another trial.

Stimuli were counterbalanced so that each stimulus appeared in each position equally often. Each serial position was tested equally often. On each trial the following were recorded: probe stimulus, correct answer, subject's response, and latency of response.

Procedure

All instructions were given by the speech synthesizer. Participants were shown the home key and asked to touch it. They were then shown a stimulus display and instructed to press the home key again to see a stimulus matrix in the first position. The subjects were instructed to look at the stimulus matrix and try to remember it. They were then told to press the home bar to see the rest of the stimulus matrices and were allowed to view

each one for as long as they wanted. After a stimulus item appeared in each position, the probe stimulus appeared in the position above the row of six stimuli. The subjects were told to touch the place where they remembered seeing the probe stimulus. If the subject's response was correct, a beep was presented, but if the response was incorrect, a click was heard. The position of the answer flashed on and off once after the subject responded. There were 3 practice trials and 144 test trials.

Results

Parameters

There were 9 measures for the PR task. These variables included measures of short-term memory capacity, primacy, recency, decision time, and response bias. *PR/ERROR* short-term memory capacity was measured by the number of errors, which could range from 0 to 144. *PRD/MEAN* was mean decision time for 144 trials and was intended to index time to access memory. *PR/BIAS* Chi-square was used to compare each participant's actual distribution of responses to correct distribution of 24 per position. Significant chi-squares were coded as 1 for *PR/BIAS*, *PRD/T2*, *PRD/T34*, and *PRD/T56*. Mean decision times of correct responses for the first two positions (*PRD/T2*), the middle two positions (*PRD/T34*), or the last two positions (*PRD/T56*) were used as times to respond after probes were presented. *PRSM*, *PR/ERR34*, and *PRPM*: Error rates for the first two positions (*PRSM*), the middle two positions (*PR/ERR34*), and the last two positions (*PRPM*) were calculated. *PRSM* is viewed as a measure of secondary memory; *PRPM*, of primary memory (see Figure 1).

Descriptive Statistics

Means and SDs are presented in Table 5. Participants with mental retardation made many more errors than did college students

Table 5
Means, SDs, Reliabilities, and Correlations With WAIS-IQ of Parameters from Reaction Time (RT) and Probed Recall (PR)

Task/Variable	College students		Mentally retarded		Combined groups		Reliability	r_{10}
	Mean	SD	Mean	SD	Mean	SD		
Reaction time								
RT/MEAN	377.00	28.33	554.33	269.50	463.17	209.83	.96	-.47
RT/SD	11.33	9.67	32.07	18.17	21.67	33.67	.87	-.36
RT/SLOPE	-8.67	6.83	.67	18.17	-.17	13.67	.77	-.05
RT/INT	374.67	38.17	552.50	257.17	463.50	202.67	.90	-.48
RT/ERRORS	4.15	2.34	5.96	7.18	5.06	5.35	.93	-.22
Probed recall								
PR/ERROR	57.40	24.10	103.15	9.57	80.28	29.4	.96	-.78
PR/BIAS	2106	353	2723	978	2214	735	.96	-.20
PR/BIAS	10.43	9.52	59.80	31.90	34.61	33.80	.87	-.78
PRD/T2	2209	397	2344	920	2276	702	.77	-.13
PRD/T34	2318	488	2443	1145	2381	872	.76	-.13
PRD/T56	1792	320	2182	937	1987	718	.90	-.32
PRSM	22.60	12.00	41.20	3.97	31.90	12.90	.96	-.72
PR/ERR34	21.75	9.90	36.50	4.56	29.50	10.60	.93	-.66
PRPM	13.05	5.18	25.60	8.41	19.32	9.37	.89	-.69

at all serial positions, and they showed greater response bias. Decision times of the groups were not significantly different.

Reliabilities and Correlations

For the combined groups, all error variables had high split-half reliability, the lowest being .89. Except for PRPM, error reliabilities were higher for college students than for participants with mental retardation.

The correlation with IQ that differed between the two groups was that for the variable *PREFERRED*: $r = .43$ for subjects with mental retardation and $r = .03$ for those without mental retardation. The correlations between IQ and the variables *PRSM*, *PREFERRED*, and *PRPM* were all very high. These data indicate that IQ is highly related to both the primary and secondary short-term memory.

STERNBERG, SEARCI (ST)

ST measures high-speed memory scanning (Sternberg, 1966, 1975). Subjects were required to memorize a set of from 1 to 6 digits and then indicate whether a subsequently presented "probe stimulus" was or was not a member of the memorized set. The ST measures are slopes and *y*-intercepts of RT across set size. Slopes are used to index memory scanning rate and *y*-intercepts, to reflect speed of encoding. Sternberg (1966, 1975) found that RT increases with size of the positive set (stimuli from the memory set), suggesting that subjects search through memory items serially in order to find a match. Also, the RT slope for the negative set (stimuli not in the memory set) paralleled that of the positive set, and its intercept was slightly higher. A search for a negative item must be exhaustive so the higher intercept indicates a self-terminating search of the positive set.

Persons with mental retardation have steeper slopes than do those without mental retardation (Harris & Elcer, 1974; Maisto & Jerome, 1977; Phillips & Nettiebeck, 1985), and encoding speed (Harris & Elcer, 1974;

Silverman, 1974) indicates slower scanning rates. Inconsistencies in the literature on this matter are probably due to methodological factors (see Silverman, 1974, in regard to scanning and Maisto & Jerome, 1977, in regard to encoding).

Method

For the ST we used sets of one, two, or three stimuli followed by a probe stimulus, which could be positive (matching) or negative (not matching). Each of the three memory sets and their corresponding negative probe sets were the same from trial to trial. Set sizes were not blocked, however, so stimuli changed from trial to trial.

Task

Subjects touched a home key (small bar at the bottom of the display) to initiate each trial and continued to touch it until prompted to respond. If the subjects lifted their fingers off the home key during a trial, a buzz sounded, the screen was cleared, and the trial was readministered. When the home bar was touched to begin a trial, a focus point was displayed in the center of the screen for 1.5 seconds. Memory set stimuli were then displayed successively for 1.5 seconds each at the center of the screen. Immediately following the presentation of the memory set, two matrices were displayed in the middle of the screen, 2 cm apart. The left matrix was always a probe stimulus, either a stimulus from the memory set or a distractor stimulus. The right matrix remained completely blank throughout the task. Subjects were instructed to touch the probe stimulus if it had appeared in the previous set and to touch the blank matrix if the probe had not appeared. Each trial ended with the subject's response. A correct response was indicated by a beep, an incorrect response by a click. The screen was then cleared until the home bar was touched again to initiate the next trial.

Each of the three memory set sizes was presented 36 times. The position of the matching stimulus, the position of the correct response (probe stimulus or no match), and set size were counterbalanced across trials. All participants received the same random order of trials.

The following measures were recorded for each trial: number of stimuli displayed (one, two, or three), position of the probe stimulus, the subject's response, decision time (the time from the presentation of the probe stimulus to the lifting of the finger from the home bar), and movement time (the time from lifting of the finger to touching either the probe stimulus or blank matrix).

Procedure

Subjects were told that speed as well as accuracy of response were important. Eighteen practice trials (6 trials per set size) followed. The task stimuli and distractor stimuli used during the instructions and practice trials were identical to those used during the experimental trials.

Results

One subject from the mentally retarded group was excluded from analysis because of response bias. Means for this group were substituted for the missing data of this subject.

Parameters

The following parameters were obtained from ST for each subject. *STDDPM* was the mean decision of all trials for which the probe stimulus matched one of the memory set stimuli. *STTAM* was the mean decision time for all trials for which the probe stimulus was absent from the memory set. *STMM* and *STMM* were mean movement times for the positive set and the negative set, respec-

tively. *STDP%*: Decision time means computed for each set size from trials in which the probe stimulus matched a memory set stimulus were regressed on set size to calculate slope. *STDA%* was the slope of decision time by set size computed for negative trials. *STMP%* and *STMAS* were the slopes of movement times by set size for positive and negative sets, respectively. *STDP_I* was the intercept of *STDP%*. Similarly, *STDA_I* was the intercept of *STDA%*. *STDP_I* was the intercept of *STDP%*, and *STMA_I* was the intercept of *STMAS*. *STEP* was the percentage of errors made for the 54 positive set trials. *STE_A* was the percentage of errors for negative set.

Descriptive Statistics

College students showed the same pattern of results found in Sternberg's (1966) work and similar studies (see Table 6). *STDP%* and *STDA%* (28.33 msec and 29.83 msec, respectively) were positive, indicating a serial memory search, and equal, indicating an exhaustive search. *STDA_I* (756.67 msec) was slightly higher than *STDP_I* (716.67 msec). However, the actual scanning (*STDP%* and *STDA%*) and encoding rates (*STDP_I* and *STDA_I*) did not match Sternberg's findings of 38-msec slopes and (approximately) 400-msec intercepts, which is probably attributable to the difference in stimuli used.

Participants with mental retardation performed oppositely from college students. Their *STDP%* and *STDA%* were negative and drastically different from each other (-520.33 msec and -34.62 msec, respectively). Also, *STDP_I* was higher than *STDA_I* (2867.17 and 1734.00, respectively), just opposite to expectations. Error rates for subjects with mental retardation were high (*STEP* = 28.95, *STE_A* = 29.83), and, although error trials were excluded from analyses, the task was too difficult for many of the participants with mental retardation. The negative slopes reflect lower decision times as the set size increased, suggesting that subjects guessed as the task became more difficult.

Table 6
Means, SDs, Reliabilities, and Correlations With WAIS-III of Parameters From Sternberg Search Task (ST)

Variable	College students		Mentally retarded		Combined groups		Reliability	r_{ρ}
	Mean	SD	Mean	SD	Mean	SD		
STDPM	723.00	181.70	1646.47	893.23	1210.43	1210.43	.47	-.63
STDAM	25.17	192.05	1664.70	1365.48	1245.00	1026.15	.83	-.42
STDPS	28.33	48.37	-520.37	822.48	-246.20	538.98	.94	.52
STDAS	29.83	70.72	-34.62	534.27	2.33	377.58	.44	.12
SDPI	116.67	194.15	2687.17	2434.68	1702.93	1974.78	.95	-.58
STDAI	165.67	245.60	1734.00	959.45	1249.68	1447.58	.67	-.62
STDAM	344.83	98.58	557.55	532.67	401.57	109.78		
STMAS	16.67	30.22	-40.05	157.43	-11.72	115.52		
STMS	19.50	23.28	-61.07	465.95	-20.92	328.17		
STMPI	211.67	93.60	637.62	671.87	424.98	520.15		
STMAI	194.67	89.05	683.95	1396.97	439.27	1007.97		
STEP	4.94		28.95		16.17		.58	-.65
STEA	3.33		29.83		16.39		.95	-.68

Reliabilities and Correlations

Several reliabilities were high (STDAM, .88; STDPS, .94; STDPI, .95; STEA, .95). Low reliabilities on STDPM, STDAS, and STDAI in the combined group (.47, .44, and .67, respectively) reflect contamination of high reliabilities for college students (.93, .89, and .80, respectively) by low reliabilities for participants with mental retardation (.34, .31, and .63, respectively). Reliabilities of STDAI (.67) and STEP (.58) were moderate.

The correlations of greatest concern in this study were those of IQ with scanning (STDPS and STDAS) and encoding (STDPI and STDAI) measures. STDPS correlated .52 with IQ and STDAS correlated .12. Subjects with higher IQs had higher scanning rates for positive sets. Although the reverse was expected (Harris & Elser, 1974; Maisto & Jerome, 1977), this correlation is understandable because of the high negative slope for participants with mental retardation. On the other hand, the STDAS correlated minimally with IQ, suggesting no relation between scanning rate and IQ when the probe stimulus is absent.

Correlations of STDPI and STDAI with IQ (.58 and -.62, respectively) revealed that as IQ increased, intercept, or encoding speed, decreased. These correlations were not unexpected. Though there has been no agree-

ment as of yet regarding group differences in intercept among individuals with and without mental retardation, Harris and Elser (1974) found that intercepts of subjects with mental retardation were higher than those of their MA-matched intellectually average peers.

Ideally, the task would be easy for all subjects, and error rate would not have correlated with IQ. The best predictor of IQ was error rate: STEP correlated -.65 with IQ, whereas STEA correlated .68. Although pilot work had suggested that the task could be done reliably by persons with mental retardation, it appears to have been too difficult when included in a longer battery. In the future researchers might use blocked trials and many more practice trials to ensure that the positive set is well-learned.

SELF-PACED PROBE (SP)

Many studies show that persons with mental retardation have a rehearsal deficiency. Ellis (1970) was the first to suggest that because primary memory was intact in subjects with mental retardation and secondary memory was not, their rehearsal must be faulty because it transfers information from primary memory to secondary memory. Ellis and Dugas (1968) and Belmont and Butterfield (1977) required subjects to pace themselves through a probe memory task, pausing as

they wished to study each of six or seven stimuli. Patterns of pause time across serial positions were used to index rehearsal strategies. Subjects without mental retardation paused longer at Position 3 or 4 than at other positions, suggesting cumulative rehearsal. Those with mental retardation, however, produced just and "flat" looking times when plotted against serial position, indicating little or no rehearsal.

Method

The SP was designed to measure rehearsal strategy in a probed memory task. As in previous work, subjects were allowed to study list items one at a time for as long as they wanted. After having studied all of the items, subjects were given a probe stimulus and asked to indicate the position at which it was presented.

Stimuli and Task

All 24 standard stimuli were used in random combinations of six, each of which was presented at a different position.

When the home key was touched, a beep informed the subject that the trial was about to begin, and unfilled matrices appeared on the screen. If the home key was still being touched, one of the 24 stimuli appeared, filling the left-most unfilled matrix. In order to view each of the remaining stimuli, subjects had to lift their fingers off the home bar and touch it again. After the subject viewed all six stimuli, one of the six stimuli appeared in the position above the row. The subject had to recall the position that the probe stimulus had appeared in and touch that position on the screen. If the answer was correct, the voice synthesizer said "yes;" if the answer was incorrect, a click sounded.

The number of trials, and the stimuli used on each trial, was identical to that used for SD and PR. On each trial the following

data were recorded: probe stimulus, correct answer, subject's response, looking time (time that the home bar was pressed for each position), and latency of response.

Procedure

College students required from 40 to 60 minutes, and subjects with mental retardation, 50 to 75 minutes to complete the task. All task instructions were given by the voice synthesizer. Thus, subjects were first shown the home bar and requested to touch it. They were then shown the stimulus display and instructed to press the home bar again to see a stimulus in the first position. Subjects were instructed to look at the stimulus and try to remember it. They were then told to press the home bar to see the rest of the stimuli and view each one as long as they wanted. After a stimulus appeared in each position, the probe stimulus appeared in the position above the row of six stimuli. Subjects were told to touch the place where they remembered seeing the probe stimulus. The position of the correct answer flashed on and off once after the subjects responded. There were three practice trials.

Results

One college student's data were lost due to equipment failure, and the other college students' means were used in their place.

Measures

Twelve measures were analyzed. *SPDZALL* was the mean looking time per stimulus. *SPSDALL* was the SD for all trials of the mean looking times for each position. A measure of variability of looking time, it was an indicator of strategy use. *SPDTCOR*, the looking time for correct trials, was calculated in the same manner as for *SPDZALL*, except

that only correct trials were considered. SPDTANS Decision time was measured from the onset of the probe stimulus until the subject touched one of the empty matrices. Data from all trials were averaged for each subject. SPDTANS/CORR. The decision time for correct answers was calculated in the same way as for SPDTANS, except that only correct trials were averaged. SPERROR was the number of incorrect trials. Its value could vary from 0 to 144. SPSCORR and SPDINC were the SRs of looking times for correct trials only and incorrect trials only, respectively. SPSTOPE, SPZSTOPE, SPINT, and SPZINT: SPSTOPE was the slope of mean looking times for each serial position regressed on serial position. This parameter was a measure of strategy use, as it was hypothesized that the subject's looking time would partly be a function of how far the item was from the end of the list (and the probe onset). The intercept was also computed from these data (SPINT). In addition, the looking times were transformed to z scores, and the slopes (SPZSTOPE) and intercepts (SPZINT) were computed to remove the effects of effort (see Belmont, Ferretti, & Mitchell, 1982).

less time, had flatter looking times across positions, and made many more errors than did the college students.

Reliabilities and Correlations

Within-group reliabilities were fairly consistent, with the exception of SPERROR. For college students, the reliability was .97, and for subjects with mental retardation, .69. Between groups, reliabilities were all above .90.

Several IQ and task measure correlations differed for the two groups. The SPSDALL variable correlated .45 with IQ for the college student group and .02 for the retarded group, the SPSCORR variable correlated .39 for the college students and .16 for the retarded group, and the STOPE variable correlated .46 for the college students and .08 for the retarded group. Looking at the correlations of SPERROR with the various strategy measures for college students, none of the measures was significantly related to SPERROR, with the exception of SPDINC, $r = -.46$, $p < .05$. For subjects with mental retardation, SPSCORR correlated .45 with SPERROR and was the only significant correlation.

The SPERROR variable was significantly related to IQ, $r = -.87$, $p < .01$, as were the SPDTANS and SPDTANSCORR variables, $r_s = .59$ and $.55$, respectively, $p_s < .01$. Some of the measures of rehearsal or strategy use,

however, did not appear to be good predictors of either IQ or SPERROR. The best predictor of SPERROR was the SPDTANS variable, $r = -.62$, $p < .01$. The longer subjects viewed stimuli, the better their recall, as indicated by the SPDTALL-SPERROR correlation, $r = -.40$, $p < .05$. Although SPDINC had the highest correlation with SPERROR, $r = -.48$, $p < .01$, the interpretation of this relation is not easily accomplished within the framework of a self-paced task.

These results cannot be directly compared with those obtained by Belmont et al. (1982) as the task demands were different and probably explain the discrepancy. However, the present relation between looking time (SPDTALL) and recall (SPERROR) is comparable to that obtained by Belmont et al.

STIMULUS DISCRIMINATION (SD)

Stimulus identification tasks typically require the subject to select a stimulus previously viewed from a matrix of stimuli varying along several dimensions. Previous researchers have found that subjects with mental retardation have an identification deficit (Smith, Kaufman, Dutch, & Frost, 1975). Carnso and Deltzman (1983a) reported that identification abilities of adults with mental retardation are deficient in rate but not qualitatively different from those of college students. This process, if deficient, may result in other information-processing deficits that are dependent upon initial encoding or identification of information.

Method

We used a six-position match-to-sample task to assess stimulus discrimination. A home key appeared at the bottom of the screen. When it was touched, a beep sounded and was followed immediately by one of the 24 stimuli centered above a horizontal row of six stimuli, one of which was identical to the probe stimulus. The five distractor stimuli were randomly selected from the remaining 24. If the home key was released, the stimu-

lus display disappeared, leaving only blank stimulus boxes (unfilled matrices) on the screen. When the home key was pressed again, the display reappeared. The trial ended when the subject pressed one of the six blank stimulus boxes to indicate the position of the display stimulus that matched the standard stimulus. At this point, the entire screen was cleared and the speech synthesizer said, "next."

If the subject's response was incorrect, the stimulus display information was recorded to be randomly inserted later. The error trial was never readministered on the following trial unless an error was made on the last trial, in which case it would be presented immediately afterwards. This procedure of inserting an error trial was not apparent to the subject, nor were subjects told that error trials would be repeated. Trials were readministered until a correct response was obtained for all displays. All subjects had 144 correct responses.

Each stimulus appeared as the standard six times, with the correct answer appearing once in each serial position, for a total of 144 trials. Order of presentation of stimuli and the position of the correct answers was random, with each subject receiving the same random order. On each trial the following were recorded: standard stimulus, correct answer, subject's response, position and identity of distractors, time that the home bar was pressed, and the time from the release of the home bar until one of the blank stimuli was touched. In timed tasks of this kind, it is important to record decision time independently of movement time. In the present experiment, both decision time and movement time were recorded independently, with decision time being the length of time the subject touched the home bar and movement time being the time between releasing the home bar and touching an empty matrix.

Procedure

College students required 20 to 30 minutes to complete the task, and subjects with

Table 7
Means, SDs, Reliabilities, and Correlations With WAIS-III IQ of Parameters From Self-Paced Probe Task (SP)

Variable	College students		Mentally retarded		Combined groups		Reliability	r_s
	Mean	SD	Mean	SD	Mean	SD		
SPDTALL	2044	7.99	1290	1042	1657	1018	.99	.34
SPDTCORR	2019	837	1429	1306	1716	1129	.99	.24
SPDTANS	2207	443	1514	553	1851	608	.97	.59
SPDTANSCORR	2071	441	1445	528	1750	576	.99	.55
SPERROR	39.45	23.60	146.85	8.81	73.15	38.40	.98	-.87
SPSDALL	340	294	203	216	269	263	.95	.18
SPSDCORR	336	336	236	203	285	246	.94	.11
SPSDINC	486	451	204	230	346	380	.99	.34
SPSTOPE	-108	192	-72	111	-89	155	.94	-.02
SPZSTOPE	3.16	5.18	2.75	4.61	2.95	4.83	.91	.03
SPINT	2397	1187	1690	1599	2029	1442	.98	.19
SPZINT	12.05	19.10	10.15	16.19	11.08	17.80	.91	.04

mental retardation required from 25 to 50 minutes. There were three practice trials and 143 test trials.

Results

One college student's data were missing from the analysis of the SP task, due to computer failure. When administering the task to the subject, when readministering the task to this subject, there was another equipment problem. Group means were used in place of this subject's data.

Nine variables were analyzed. *SDMEANDT* was the mean time the onset of the stimulus display until the subjects removed their fingers from the home bar. *SDMEAMMT* was the mean time it took a subject to touch one of the empty matrices, after lifting his or her finger off the home key. *SDPEROR* was the number of incorrect responses (0 to 144) made by a subject. *SDTTSLOPE* was the slope of each subject's mean decision time for each stimulus, regressed on the group mean decision time for each stimulus. This variable indicated how the subject's decision time was affected relative to his or her group's, by increasing the stimulus difficulty level. *SDMTTSLOPE* and *SDMTINT*: As previously described, the slope (*SDMTSLOPE*) and intercept (*SDMTINT*) of each subject's mean movement time for the stimuli were computed. *SDTROSSLOPE*: Slope of decision time across serial position was computed for each subject, as was intercept (*SDTROSSINT*).

Descriptive Statistics

The means and SDs for both groups are presented in Table 8. The subjects with mental retardation responded slower for both decision time and movement time components and had a steeper slope. The slope differences indicate that their identification of stimuli was slowed more by increases in

stimulus complexity than it was for the college students.

Reliabilities and Correlations

The reliabilities for both groups were comparable, with the exception of the *SDPOSSLOPE* variable, where the reliability was .66 for college students and .15 for participants with mental retardation. Several variables correlated highly with IQ for the latter group but not for college students: for *SDMEANDT*, the correlation with IQ for college students was .02, and -.70 for subjects with mental retardation. For the *SDDTTSLOPE* variable, the correlations with IQ were .02 and -.63 for subjects with mental retardation and college students, respectively. For *SDPOSSINT*, the correlations were -.03 for college students and -.63 for subjects with mental retardation.

The *SDMEANDT* and *SDDTTSLOPE* are excellent predictors of IQ. The faster response times for the college students do not appear to be due to a speed-accuracy trade off, as the time-*SDPEROR* correlations were all not statistically significantly different than zero.

TACHISTOSCOPIC FULL REPORT (TFP)

This task sought a measure of the time needed to determine whether two stimuli are the same or different. Nettelbeck (1982, 1985) has shown that inspection time is a good predictor of individual differences in intellectual ability for a task as simple as deciding whether two lines are different lengths.

Method

Task

This task was composed of 20 blocks of trials of variable numbers. Each trial block began with a stimulus presented for 17 msec. When a subject responded incorrectly, the

Table 8
Means, SDs, Reliabilities, and Correlations With WAIS-IQ of Parameters From Stimulus Discrimination (SD) and Tachistoscopic Full Report (TFP)

Variable	College students		Mentally retarded		Combined groups		Reliability	r _s
	Mean	SD	Mean	SD	Mean	SD		
Stimulus Discrimination								
SDMT	2529	675	5794	2927	4203	4203	.99	-.70
SDMTI	330	41	456	212	395	166	.96	-.44
SDPEROR	9.10	9.52	20.85	22.70	15.13	18.50	.84	-.32
SDTTSLOPE	5.26	2.30	19.18	11.60	12.40	10.90	.71	-.72
SDMTINT	1193	325	921	1755	1054	1269	.19	-.08
SDTROSSLOPE	-9.05	20.10	16.60	42.90	.07	.60	.96	-.25
SDMTINT	574	577	402	235	486	439	.60	-.20
SDPOSSLOPE	34.94	88	49.18	197	42.24	152	.04	-.05
SDPOSSINT	2406	582	5641	3163	4065	2801	.97	-.67
Tachistoscopic Full Report								
TFMD	31	9	75	44	53	39	.90	-.68
TFDIAL	23	7	54	36	39	30	.67	-.61
TFDTR	655	407	683	296	689	306	.98	-.10
TFDTR	645	402	679	309	669	369	.98	-.10
TFDTR	733	402	701	294	717	420	.86	-.19
TFMTAL	587	324	676	418	631	377	1.00	.06
TFMTCR	575	315	667	436	626	384	.99	.02
TFMTWR	634	410	694	402	659	407	.96	.17

presentation time on the following trial was lengthened by 33 msec. When a subject responded correctly, the following trial had the same presentation time. Each block ended when the subject responded correctly on three consecutive trials. The threshold value for each block was defined as the last presentation time. Each trial began when the subject touched the home bar. A fixation point (a plus sign) appeared centered in the area of the screen where the stimuli would appear.

After a 3-second delay, two stimuli were presented that were either the same or different. Same and different trials were equally probable and were randomly determined. After the two stimuli were presented, a mask consisted of stimuli with all squares filled, appearing in the same position where the test stimuli had been presented.

The subject responded by touching a filled stimulus matrix on the left of the screen to indicate that the stimuli were the same and an unfilled stimulus matrix on the right of the screen to indicate that they were different. Subjects were given one practice block of trials before the test trials began. Subjects

were not told that incorrect responses lengthened presentation time, and, in fact, it appeared that most subjects were unaware that presentation time varied systematically within a block of trials.

Results

Measures

In addition to presentation time, there were three dependent measures: decision time, movement time, and the correctness of the response. *TFMN* was the mean threshold for the last trial of each of the 20 blocks, and *TFMD* was the median. *TFDTR* was the mean decision time for all trials (i.e., time from the end of stimulus presentation until the subject lifted his or her finger from the home key. *TFDTR* was *TFDTR* calculated only for correct trials. *TFMYAL* was *TFMYAL* calculated only for correct trials. *TFDTR* was *TFDTR* calculated only for correct trials. *TFDTR* was *TFDTR* calculated only for incorrect trials. *TFMYAL* was the mean movement time for all trials (i.e., time after the subject lifted his or her finger from the home key until one

of the response positions (same or different) was touched. *TPMVAL* was TPMVAL, calculated only for incorrect trials.

Descriptive Statistics

Descriptive statistics are shown in Table 8. The major variables of interest were the threshold measures for which there were large mean differences.

Mean decision and movement times were very similar for college students and participants with mental retardation, an unusual finding indeed.

Reliabilities and Correlations

Split-half reliabilities for the six movement and decision time measures were moderately to highly reliable (.71 to .99). Most of these variables correlated poorly with Wechsler IQs (.30 to -.17).

Only threshold times (TMN and TMD) correlated highly with IQ. Median threshold times correlated -.57 with intelligence.

TACHISTOSCOPIC PARTIAL REPORT (TP)

This tachistoscopic task required subjects to report information about a part of a visual display at various intervals after presentation. We expected that subjects with higher IQs would be able to process more information and would lose information from memory at a slower rate. Therefore, overall proportion correct should correlate positively and slope of percentage correct over time should correlate negatively with IQ.

Method

TP consisted of 128 trials to allow counterbalancing of four positions, four time offsets, and two response alternatives and to produce four data points for each combination of positions, time offset, and response alternative.

A trial began when the participant pressed the home key, which produced a presentation of four stimuli chosen from the set of the 24 previously described. Presentation of the stimuli was controlled so that all the stimuli appeared the same number of times across the task. A trial commenced with the presentation of a fixation point (3 seconds) in the top half of the screen. The fixation point was followed by the presentation of four stimuli arranged in a square around the fixation point. These four squares appeared for 200 msec. The screen then became blank.

After a delay of 0, 100, 300, or 700 msec, a stimulus appeared in the lower left hand corner, a blank square appeared in the lower right hand corner, and a dotted line outlined one of the four original stimulus positions. Half of the time the stimulus appearing in the lower left corner was the same as the stimulus that had been in the position now outlined by dots; the other half of the time, it was different.

The subject's task was to indicate whether the stimulus that appeared in the position surrounded by dots matched the probe by pressing either the stimulus in the lower left corner (probe) or by pressing the empty square in the bottom left of the screen (no match).

Procedure

This task required approximately 20 minutes to complete. Subjects were instructed to keep their head 24 cm from the screen in front of them and were shown the appropriate distance. The task began with five practice trials.

Results

Measure

Decision time, movement time, and response choice were used to derive eight measures. *TPYC* was the proportion of correct trials. Correlation of *d'* and *TPPC* was

.99, so only the simpler measures of percentage correct are reported. *TPP1CR* was the mean decision time for correct trials and *TPP1WR* for incorrect trials. *TPMTCR* and *TPM1WR* were mean movement time for correct and incorrect trials, respectively. *TPPCSL* was the slope of percentage correct over the four delay intervals computed for each subject. *TPP2SL* was the slope of decision time over the four delay intervals computed for each subject. *TPM1SL* was the slope of movement time over the four delay intervals computed for each subject. Intercorrelations are not reported because they correlated with the foregoing measures.

Descriptive Statistics

There were large group differences for all variables except slopes (Table 9). College students were faster and more accurate than were participants with mental retardation, who performed near chance (.50).

Reliabilities and Correlations

The most reliable measures, $r > .90$, were mean decision times. The least reliable were slope variables ($< .56$). Proportion correct was highly correlated with IQ, even though within-group correlations were low. Although it is impossible to compare relative decay rates of the two groups, there is no doubt that accuracy on this task predicts

differences in IQ.

General Results and Discussion

In this section, the results from all tasks were considered collectively. Discussion was confined to the variables listed in Table 1, which were of primary theoretical interest. The smaller number of variables was still large for the number of subjects used here. Care was taken to avoid interpretation of chance results that small numbers of subjects can produce. Although only large and consistent effects were interpreted, the results reported here should be considered preliminary.

Mean Differences

The 31 variables reported in Table 1 were each subjected to a one-way analysis of variance to determine whether subjects with mental retardation performed differently than did college students. Of the 31 variables, 24 were statistically significant in the expected direction, $p < .05$. Five variables (RTSD, SPSPDALL, PRSM, RLTIME, and LRBIAIS) were marginally statistically significant, $p < .10$. Only two variables, RTERROK and RTSLOPE, did not discriminate between groups. Unfortunately, the differences demonstrated by our measures are so large and ubiquitous that they are difficult to relate to the modal model presented earlier.

Table 9
Means, SDs, Reliabilities, and Correlations With WAIS-III of Parameters From Tachistoscopic Partial Report (TP)

Variable	College students		Mentally retarded		Combined groups		Reliability	IQ
	Mean	SD	Mean	SD	Mean	SD		
TPPC	62.5	9	51.8	4	57.1	9	.78	.61
TPOTCR	1520	592	1193	426	1367	536	.92	.28
TPOTWR	1732	644	1216	400	1474	593	.96	.43
TPPESL	-4.3	15	-.3	19	-2.3	17	.53	-.18
TPDSCR	-350	143	-.300	460	-340	440	.00	.07
TPPSWR	-400	430	-110	890	-250	710	.56	.24
TPMTCR	418	154	673	492	545	369		
TPM1WR	474	446	678	173	576	349		

Ordering of Differences

Although there were large and statistically significant differences between groups, there also were differences in the magnitude of these differences. One way to get an idea of which processes are most important in intellectual functioning is to consider the standardized magnitude of the differences between groups (i.e., the *t* value). The rank order of each variable is shown in Table 2 in parentheses after the variable name. The top 10 variables showing the largest differences between groups (*t* values in parentheses) were: SPERROR (11.98), LRTIAL (9.65), MYTRIAL (8.58), PERROR (7.89), PRSM (6.60), PRBIAS (6.49), PRPM (5.69), SIDERRORS (5.28), TPRROP (4.95), and SDDT (4.87). Nine out of 10 of these variables are measures of correct responding. Eight of the 10 measures with the lowest *t* values are measures concerned with latency or speed. It appears that correct response measures are the most sensitive to individual differences in intellectual ability.

Of greater theoretical interest are the kinds of processes measured by the parameters showing the largest differences. The top seven parameters come from tasks of memory or learning. The other three come from tasks measuring perceptual discrimination. Obviously, these very simple tasks are capable of detecting substantial differences between intelligence groups.

Principal Component Analysis

One possible explanation for the observation that basic cognitive tasks predict standard intelligence measures is that both contain a single, common source of variance, often called general intelligence, or *g*. A common method for estimating the amount of *g*-loadness of a battery of tests is to determine the proportion of variance accounted for by the unrotated first principal component. In a typical battery of intelligence tests (or subsets of a single test), the

first principal component typically accounts for from 60% to 80% of the variance.

In order to estimate the amount of variance accounted for by the first principal component, we conducted a principal component analysis using the 31 variables listed in Table 1 on the groups separately and for both groups combined. The correlations upon which the analyses for the whole sample are based are shown in Table 10, which includes both corrected and uncorrected correlations. The unrotated first principal component accounted for 19%, 36%, and 48% of the variance for college students, subjects with mental retardation, and both groups combined, respectively. None of these values fall within the range typically obtained for principal components analysis of batteries of intelligence tests.

The most direct interpretation of this finding is that parameters from this battery of basic cognitive tests have much lower intercorrelations than do intelligence tests with each other or subsets within a test (Detemman & Daniel, 1980). Because the parameters from the basic cognitive tests combine to predict as much variance as is accounted for by the correlation between intelligence tests, it cannot be the case that all of the parameters contain *g* but simply have less of it. If all of the basic cognitive tasks were measuring the same thing, they would not combine to predict as much variance as they do. Therefore, it seems reasonable to conclude that the parameters obtained from the basic cognitive tasks used here account for different sources of variance. Thus, both the multiple correlations of the basic parameters with intelligence and the low amounts of variance accounted for by the unrotated first principal component argue for these parameters as being measures of at least partially independent sources of variance.

Prediction of IQ by Basic Tasks

In order to determine to what extent IQ was predictable from basic cognitive tasks,

Table 10
Correlation Matrix for 31 Basic Variables and WAIS-R Full-Scale IQ

Variable	LRTIAL	LRTIME	LBBIAS	LRTIAL	RLTIME	LBBIAS	LRTIAL	RLTIME	LBBIAS
LRTIAL	1.00								
LRTIME	-0.22	1.00							
LBBIAS	0.55	-0.32	1.00						
LRTIAL	0.88	-0.37	0.55	1.00					
RLTIME	-0.20	0.56	-0.22	-0.22	1.00				
LBBIAS	0.47	-0.29	0.94	-0.24	0.94	1.00			
RTIMEAN	0.48	-0.34	0.45	-0.47	0.47	0.47	1.00		
RTYINT	0.01	-0.01	-0.09	0.11	-0.09	0.11	-0.09	1.00	
RTSLOPE	0.36	-0.32	0.32	-0.32	0.32	0.32	-0.32	0.32	1.00
RTISD	0.28	0.01	0.51	0.29	0.40	0.40	0.29	0.40	0.29
PERRORS	0.71	-0.29	0.47	-0.29	0.68	0.68	-0.29	0.68	0.68
PERROR	0.80	-0.33	0.66	-0.33	0.66	0.66	-0.33	0.66	0.66
PRBIAS	0.61	-0.25	0.44	-0.25	0.44	0.44	-0.25	0.44	0.44
PRSM	0.68	-0.36	0.61	-0.36	0.61	0.61	-0.36	0.61	0.61
PRPM	0.62	-0.45	0.48	-0.45	0.48	0.48	-0.45	0.48	0.48
SDPM	-0.50	0.62	0.47	-0.48	0.62	0.62	-0.48	0.62	0.62
SDPS	0.56	-0.48	0.58	-0.48	0.58	0.58	-0.48	0.58	0.58
SDPI	0.60	-0.29	0.18	-0.29	0.18	0.18	-0.29	0.18	0.18
SDAI	0.66	-0.37	0.76	-0.37	0.76	0.76	-0.37	0.76	0.76
SDTA	0.66	-0.37	0.42	-0.37	0.42	0.42	-0.37	0.42	0.42
SDTA	0.73	-0.39	0.42	-0.39	0.42	0.42	-0.39	0.42	0.42
SDTA	0.81	-0.28	0.44	-0.28	0.44	0.44	-0.28	0.44	0.44
SPERROR	-0.46	0.27	-0.24	0.27	-0.24	-0.24	0.27	-0.24	0.27
SPOTANS	-0.33	0.11	-0.30	0.11	-0.30	-0.30	0.11	-0.30	0.11
SPOTALL	-0.20	0.00	-0.23	0.00	-0.23	-0.23	0.00	-0.23	0.00
SPSDALL	0.65	-0.36	0.80	-0.36	0.80	0.80	-0.36	0.80	0.80
SDDT	0.42	-0.36	0.35	-0.36	0.35	0.35	-0.36	0.35	0.35
SDDT	0.60	-0.35	0.62	-0.35	0.62	0.62	-0.35	0.62	0.62
SDDT	0.63	-0.43	0.71	-0.43	0.71	0.71	-0.43	0.71	0.71
SDDT	0.55	-0.29	0.37	-0.29	0.37	0.37	-0.29	0.37	0.37
TPRROP	-0.59	0.44	0.44	0.44	0.37	0.37	0.44	0.37	0.37
IOFULL	-0.85	0.36	-0.56	0.36	-0.56	-0.56	0.36	-0.56	0.36
RTIMEAN	0.30	0.32	-0.03	0.23	0.23	0.23	-0.03	0.23	0.23
LRTIAL	-0.25	-0.26	0.00	-0.12	0.22	0.22	0.06	0.06	0.06
LBBIAS	0.34	0.28	-0.12	0.11	0.22	0.22	-0.15	-0.15	-0.15
LRTIAL	0.31	0.30	0.11	0.29	0.23	0.23	0.45	0.45	0.45
RLTIME	-0.17	-0.15	-0.14	-0.23	-0.05	-0.05	-0.07	-0.07	-0.07
LBBIAS	0.29	0.31	-0.02	0.20	0.49	0.49	0.24	0.24	0.24
RTIMEAN	1.00	0.98	1.00	0.98	1.00	1.00	0.98	0.98	0.98
RTYINT	0.99	1.00	0.12	0.48	0.87	0.87	0.30	0.30	0.30
RTSLOPE	0.29	1.00	0.29	1.00	0.48	0.48	0.14	0.14	0.14
RTISD	0.93	0.88	0.47	0.93	1.00	1.00	0.07	0.07	0.07
PERRORS	0.12	0.10	0.14	0.12	0.12	0.12	1.00	1.00	1.00
PERROR	0.46	0.46	0.11	0.46	0.18	0.18	0.18	1.00	1.00
PRBIAS	0.43	0.42	0.11	0.34	0.34	0.34	0.67	0.67	0.67
PRSM	0.41	0.40	0.11	0.28	0.28	0.28	0.94	0.94	0.94
PRPM	0.54	0.54	0.11	0.33	0.33	0.33	0.80	0.80	0.80
SDPM	0.86	0.84	0.33	0.81	0.81	0.81	0.56	0.56	0.56
SDPS	-0.87	-0.86	-0.19	-0.80	-0.80	-0.80	-0.44	-0.44	-0.44
SDPI	0.89	0.88	0.16	0.83	0.83	0.83	0.54	0.54	0.54
SDAI	0.55	0.52	0.30	0.52	0.52	0.52	0.54	0.54	0.54
SDTA	0.69	0.68	0.20	0.62	0.62	0.62	0.55	0.55	0.55
SDTA	0.45	0.28	0.26	0.46	0.30	0.30	0.86	0.86	0.86
SDTA	0.01	-0.04	0.31	-0.04	0.12	0.12	-0.40	-0.40	-0.40
SDTA	0.01	-0.25	-0.01	-0.16	-0.16	-0.16	-0.30	-0.30	-0.30
SDTA	-0.16	-0.17	0.05	-0.14	-0.14	-0.14	-0.27	-0.27	-0.27
SDTA	0.63	0.67	0.11	0.48	0.48	0.48	0.60	0.60	0.60
SDMT	0.81	0.82	0.11	0.73	0.73	0.73	0.41	0.41	0.41
SDERROR	0.45	0.50	-0.15	0.31	0.31	0.31	0.60	0.60	0.60
TFMEAN	0.54	0.55	0.03	0.42	0.42	0.42	0.51	0.51	0.51
TFMED	0.33	0.33	0.06	0.24	0.24	0.24	0.00	0.00	0.00
TPRROP	-0.36	-0.35	-0.15	-0.36	-0.36	-0.36	-0.17	-0.17	-0.17
IOFULL	-0.47	-0.48	-0.05	-0.36	-0.36	-0.36	-0.41	-0.41	-0.41

(continued on next page)

Table 10 (continued)

Variable	PBBIAS	PSM	PRPM	STDM	STDS	STDI
LRTIAL	0.65	0.47	0.37	0.43	-0.32	0.37
LRTIME	-0.20	-0.17	-0.11	-0.36	0.40	-0.40
LBBIAS	0.54	0.24	0.48	0.32	-0.52	0.46
LBTRIAL	0.68	0.42	0.32	0.50	-0.41	0.46
LRTIME	-0.12	-0.13	-0.00	-0.22	0.39	-0.34
LBBIAS	0.64	0.16	0.47	0.34	-0.53	0.48
LRMEAN	0.26	0.24	0.43	0.84	-0.84	0.87
LRVINT	0.25	0.23	0.43	0.81	-0.84	0.86
LRISLOPE	0.11	0.22	0.10	0.36	-0.19	0.26
RTSD	0.21	0.14	0.10	0.80	-0.78	0.82
RTRRORS	0.38	0.16	-0.68	0.03	-0.12	0.09
PRRORR	0.46	0.91	0.70	0.36	-0.25	0.30
PBBIAS	1.00	0.45	0.41	0.36	-0.35	0.37
PRSM	0.66	1.00	0.45	0.29	-0.19	0.23
STDM	0.62	0.50	1.00	0.48	-0.42	0.46
STDS	-0.51	-0.39	0.63	1.00	-0.84	0.93
STDI	0.55	0.44	0.60	0.95	-0.98	1.00
STDP	0.43	0.48	0.47	0.75	-0.50	0.61
STDP	0.72	0.51	0.56	0.73	-0.79	0.79
STDP	0.74	0.48	0.56	0.61	-0.43	0.51
STDP	0.72	0.82	0.71	0.56	-0.44	0.50
SPTRORS	-0.47	-0.42	-0.32	-0.14	-0.10	-0.10
SPTRALS	-0.25	-0.31	-0.17	-0.05	0.08	-0.17
SPTRALL	-0.26	-0.30	-0.17	-0.05	0.07	-0.07
SPSDALL	-0.18	-0.30	-0.17	-0.05	0.08	-0.07
SDT	0.66	0.62	0.72	0.73	-0.77	0.78
SDMT	0.34	0.35	0.48	0.78	-0.68	0.74
SDRROR	0.61	0.52	0.66	0.67	-0.65	0.68
TFMEAN	0.70	0.69	0.65	0.69	-0.56	0.63
TFMED	0.64	0.40	0.53	0.52	-0.33	0.42
TPPROP	-0.52	-0.39	-0.40	-0.40	-0.35	-0.38
IOFULL	-0.78	-0.72	-0.69	-0.63	0.52	-0.58
Variable	STDAI	STEP	STEA	SEPROR	SPOTANS	SPTRALL
LRTIAL	0.40	0.49	0.58	0.62	-0.24	-0.20
LRTIME	-0.18	-0.27	-0.12	-0.12	0.16	0.03
LBBIAS	-0.05	0.69	0.22	0.19	-0.03	-0.20
LBTRIAL	0.49	0.51	0.67	-0.03	-0.18	-0.04
LRTIME	0.04	-0.34	-0.05	-0.03	0.07	0.12
LBBIAS	0.02	0.71	0.33	0.17	-0.07	-0.17
LRMEAN	0.45	0.62	0.69	0.27	0.23	-0.16
LRVINT	0.41	0.60	0.06	0.29	0.18	-0.17
LRISLOPE	0.41	0.60	0.06	0.29	0.18	-0.17
RTSD	0.32	0.21	0.14	-0.05	0.37	-0.00
RTRRORS	0.47	0.58	0.08	0.07	0.31	-0.03
PRRORR	0.03	0.54	0.02	0.07	0.08	-0.03
PBBIAS	0.34	0.32	0.32	0.75	-0.15	-0.17
PRSM	0.17	0.59	0.61	0.49	-0.24	-0.16
STDM	0.27	0.23	0.23	0.70	-0.19	-0.19
STDS	0.26	0.38	0.36	0.54	-0.07	-0.12
STDI	0.26	0.38	0.36	0.54	-0.07	-0.12
STDP	0.66	0.62	0.46	0.32	0.14	-0.00
STDS	-0.36	-0.74	-0.26	-0.22	-0.17	-0.04
STDI	0.49	0.34	0.34	0.31	0.16	-0.04
STDP	1.00	0.25	0.48	0.34	-0.02	0.09
STDP	0.45	1.00	0.30	0.34	0.13	-0.22
STDP	0.62	0.51	1.00	0.34	0.13	-0.22
STDP	0.54	0.58	0.59	1.00	-0.45	0.15
SPTRORS	-0.25	-0.15	-0.40	-0.62	-0.30	-0.30
SPTRALS	-0.06	-0.33	-0.03	-0.40	1.00	0.43
SPTRALL	-0.00	-0.26	-0.02	-0.26	0.49	1.00
SPSDALL	-0.00	-0.26	-0.02	-0.26	0.23	0.68
SDT	0.51	0.78	0.58	0.60	-0.29	-0.11
SDMT	0.44	0.44	0.39	0.41	-0.11	-0.11
SDRROR	0.57	0.63	0.59	0.64	-0.42	-0.05
TFMEAN	0.60	0.57	0.77	0.57	-0.36	-0.22
TFMED	0.47	0.46	0.76	0.50	-0.33	-0.18
TPPROP	-0.35	-0.44	-0.41	-0.54	-0.33	-0.18
IOFULL	-0.62	-0.65	-0.68	-0.87	0.59	0.34

(continued on next page)

Table 10 (continued)

Variable	SPSDALL	SDDT	SDMT	SDRROR	TFMEAN	TFMED
LRTIAL	-0.14	0.43	0.26	0.34	0.41	0.34
LRTIME	-0.04	-0.25	-0.29	-0.24	-0.34	-0.18
LBBIAS	-0.19	0.74	0.38	0.23	0.49	0.18
LBTRIAL	0.04	0.51	0.24	0.39	0.54	0.43
LRTIME	0.04	-0.19	-0.07	-0.20	0.01	0.11
LBBIAS	-0.14	0.72	0.13	0.53	0.48	0.27
LRMEAN	-0.11	0.55	0.78	0.31	0.31	0.21
LRVINT	-0.12	0.60	0.79	0.36	0.44	0.17
LRISLOPE	-0.12	0.05	-0.17	0.36	0.44	0.17
RTSD	0.00	0.40	0.32	0.32	0.00	0.05
RTRRORS	-0.12	0.25	0.70	0.19	-0.22	0.12
PRRORR	-0.23	0.38	0.26	0.38	-0.08	-0.10
PBBIAS	-0.11	0.47	0.16	0.38	0.35	0.30
PRSM	-0.26	0.24	0.19	0.27	0.54	0.49
STDM	-0.11	0.59	0.37	0.49	0.20	0.15
STDS	0.03	0.62	0.57	0.53	0.49	0.35
STDI	0.02	0.93	0.75	0.69	0.57	0.36
STDP	0.00	0.70	-0.71	-0.54	-0.43	-0.16
STDP	0.09	0.32	0.32	0.56	0.50	0.24
STDP	0.09	0.32	0.32	0.56	0.45	0.30
STDP	0.09	0.32	0.32	0.56	0.45	0.30
STDP	0.09	0.32	0.32	0.56	0.45	0.30
STDP	0.09	0.32	0.32	0.56	0.45	0.30
STDP	0.09	0.32	0.32	0.56	0.45	0.30
SPTRORS	-0.22	0.34	0.24	0.39	0.39	0.25
SPTRALS	0.18	0.68	0.06	0.07	-0.19	-0.13
SPTRALL	0.68	1.00	0.06	0.06	-0.09	-0.06
SPSDALL	1.00	0.01	0.06	0.05	-0.01	-0.02
SDT	-0.08	1.00	0.45	0.84	0.51	0.23
SDMT	0.01	0.27	1.00	0.27	0.52	0.39
SDRROR	-0.05	0.89	0.45	1.00	0.37	0.17
TFMEAN	-0.09	0.66	0.60	0.57	1.00	0.90
TFMED	-0.09	0.44	0.60	0.41	0.93	1.00
TPPROP	0.15	-0.45	-0.28	-0.41	-0.40	-0.35
IOFULL	0.81	-0.70	-0.44	-0.72	-0.68	-0.61
Variable	TPPROP	IOFULL				
LRTIAL	-0.39	-0.69				
LRTIME	0.35	0.22				
LBBIAS	-0.18	-0.37				
LBTRIAL	-0.39	-0.68				
LRTIME	0.30	0.18				
LBBIAS	-0.19	-0.36				
LRMEAN	-0.21	-0.30				
LRVINT	-0.19	-0.31				
LRISLOPE	-0.19	-0.31				
RTSD	-0.15	-0.03				
RTRRORS	-0.26	-0.22				
PRRORR	-0.10	-0.13				
PBBIAS	-0.16	-0.59				
PRSM	-0.31	-0.60				
STDM	-0.15	-0.52				
STDS	-0.18	-0.49				
STDI	-0.20	-0.43				
STDP	0.18	-0.39				
STDP	-0.20	-0.42				
STDP	-0.14	-0.42				
STDP	-0.27	-0.45				
STDP	-0.19	-0.48				
SPTRORS	-0.31	-0.73				
SPTRALS	0.19	-0.39				
SPTRALL	0.09	0.21				
SPSDALL	0.09	0.11				
SDT	-0.24	-0.50				
SDMT	-0.13	-0.28				
SDRROR	-0.12	-0.52				
TFMEAN	-0.18	-0.46				
TFMED	-0.15	-0.41				
TPPROP	1.00	0.41				
IOFULL	0.81	1.00				

Note: Correlations in the upper triangular portion of the matrix are corrected for extended range due to selection by IQ.

we selected nine variables and used them in a multiple regression analysis. To obtain the nine variables, we selected one variable from each task as the most theoretically significant (in the first author's judgment). The nine variables used were: SDDT, SPDTAL, PREROR, LTRIAL, RLBIAS, STDPM, TFMEN, TPRROP, and RTMEAN. All variables were then entered into a multiple regression equation (SPSS Enter procedure).

For the combined groups, the multiple correlation was $R = .92$ (shrunken $R = .89$), which was statistically significantly different than zero, $F(9, 30) = 17.15, p < .01$. For the mentally retarded group alone, the multiple correlation was $R = .91, F(9, 10) = 5.01, p < .01$, shrunken $R = .66$. For the college students alone, the multiple correlation was $R = .76$, shrunken $R = .44$.

Other methods for obtaining multiple correlations produced essentially identical results. Within-group multiple correlations for college students were always lower than for the mentally retarded group. The multiple correlation for the combined groups ranged between approximately .75 and .92.

Because the mentally retarded and college student groups had a restricted range and the combined group had an extended range, we assumed that the population value for the multiple correlation would lie somewhere between the two extremes. The average shrunken R for the two groups separately was $.55 (.44 + .66/2)$. The shrunken R for both groups combined was .89. Therefore, we estimated that in a random sample from the general population, the obtained multiple correlation would be $.72 (.55 + .89/2)$. Because intelligence tests correlate with each other in the range of .70 to .80, this result suggests that basic cognitive tests correlate with an intelligence test as well as different intelligence tests correlate with each other. What this means is that the basic cognitive tests contained in this battery contain the same common sources of variance as are shared by different intelligence tests. There is no doubt that if the processes taking place in these basic cognitive tasks were understood, we also would understand intelligence.

Detailed Multiple Regression Analysis—The Modal Model

A major goal of this research was to test the modal model presented in Figure 1 to determine whether it is an adequate representation of individual differences. The most parsimonious result would be to find that one part of the system is severely impaired in comparison to all other parts. However, nearly every basic cognitive parameter demonstrated differences between subjects with mental retardation and college students. The deficits were so pervasive and ubiquitous that it is not possible to localize a deficit to a single process. However, the finding that mental retardation is not reflected by a single deficit in the parameters measured here does not invalidate the modal model.

For the modal model to be a valid representation of individual differences, each portion of the model should account for a unique source of variance not accounted for by other parts of the model. Ideally, the way to determine the appropriateness of this model would be to use LISREL (or some other model fitting program) to test the operationalization of the model given in Table 2. However, the number of subjects is too small for LISREL model fitting and, more importantly, LISREL is sensitive to violations of normality. The alternative adopted was to use hierarchical multiple regression to test whether various components of the model added statistically significant amounts of variance to earlier portions of the model. Multiple regression has the added advantage of being unaffected by restrictions or extensions in range. (Although the size of the multiple R will change, the regression coefficients and significance of change will be unaffected by range changes. All of the following regression analyses were done with correlation matrices corrected for extended range and results lead to identical conclusions. Results reported are for uncorrected correlations.)

For each portion of the modal model shown in Table 2, a composite was formed

of the variables listed to represent that part of the model. For example, the composite for very short-term memory was composed of the sum of TPRROP, TFMEN, and TMEED. Before combining variables, we converted each of the 31 variables to a z score on the basis of the mean and SD for all 40 subjects. Variables having a negative correlation with Full-Scale IQ were then reflected (multiplied by -1) so that all variables had positive correlations with IQ. This resulted in 10 composites representing each part of the modal model: very short-term memory, primary memory, secondary memory, tertiary memory, rehearsal, executive functioning, retrieval, coding, efficiency, output, as listed in Table 2. There were two reasons for using these composites. First, because the composites were formed a priori, they offer a strong, conservative test of the appropriateness of parts of the model. Second, the formation of composites reduces the number of variables to an appropriate range for the number of subjects available while taking advantage of all of the data.

The 10 composites were used in a series of hierarchical multiple regression analyses. In doing these analyses, it became clear that rehearsal and secondary memory accounted for very little unique variance. In all analyses, rehearsal was entered with executive functioning and secondary memory was entered with tertiary memory. This simpler form of the model implies that rehearsal is under control of executive functioning and that secondary memory and tertiary memory really constitute a single store. In addition, retrieval, stimulus coding, and output were considered low level, pervasive processes that affected nearly all parts of the system and were, a priori, entered as a block. When entered first in the order output, retrieval, and stimulus coding, these variables accounted for 20%, 23%, and 13% of the total variance in IQ, respectively. However, when stimulus coding was entered first, it accounted for all (66%) of the variance and output and retrieval accounted for none. Because it is impossible to test stimulus

coding without including retrieval and output processes, it seemed reasonable that stimulus coding should account for the variance in retrieval and output.

An important consideration in hierarchical regression is the order of variable entry. The following rules were used to enter variables because they seemed most consistent with the intent of the modal model. First, stimulus control processes (stimulus coding and retrieval and output), which affected all other processes, were entered. This procedure makes the conservative assumption that the stimulus control processes should be assigned the common variance among all processes. Second, variables occurring earlier in time were entered next in chronological order (i.e., very short-term memory, primary memory, secondary memory, and tertiary memory, in that order). Finally, models built from the bottom up which entered basic processes before more global processes (executive functioning and rehearsal and efficiency) were contrasted with top-down models that entered more global processes first because there seemed no obvious way to decide between the two alternatives.

Summary results for three separate analyses are shown in Table 11. The first is the bottom-up model that enters the basic processes of very short-term memory, primary memory, secondary memory, and tertiary memory before more global processes. As can be seen, in this approach executive functioning and rehearsal and efficiency accounted for none of the predicted variance in IQ. However, each of the other components accounted for a significant portion of unique variance, suggesting that each of these components deserve their status as a separate process.

The second analysis regards efficiency as a general characteristic of the system and reflects an orientation similar to that expressed by Eysenck (1982). According to Eysenck, mental speed is a major index of mental efficiency. Because efficiency consists of RT parameters, it should index efficiency as defined by Eysenck. According to

Table 11
Multiple Regression Tests of Individual Differences in the Modal Model

Variable	R ²	R ² change	F
Bottom up			
RET+CODE+OUT	.56	.14	14.98*
VSTM	.70	.10	16.45*
PM	.80	.05	17.72*
SM+TM	.85	.05	5.77*
EXEC+REH	.85	.00	.01
EFF	.86	.002	.32
Partial top-down			
RET+CODE+OUT	.19	—	8.89*
VSTM	.56	.37	9.62*
PM	.70	.14	16.11*
SM+TM	.81	.11	17.93*
EXEC+REH	.86	.05	5.88*
Full top-down			
EFF	.19	—	8.89*
RET+CODE+OUT	.56	.37	9.62*
EXEC+REH	.71	.15	9.21*
VSTM	.74	.03	3.41**
PM	.81	.07	10.67*
SM+TM	.86	.05	4.75*

Note. See Table 2 for explanations of abbreviations.
* $p < .05$. ** $p < .10$.

Eysenck's position, efficiency should account for a substantial portion of the variance if entered first. The fact is that efficiency only accounted for a significant amount of variance when entered first, as shown in the partial top-down case of Table 11, and even then it accounted for only 19% of the total variance in IQ. This analysis suggests that the variance attributable to efficiency can be accounted for by stimulus control processes (stimulus coding and retrieval and output) and is not the only factor accounting for intellectual differences.

The full top-down analysis of Table 11 enters executive functioning processes before the basic processes of very short-term memory, primary memory, secondary memory, and tertiary memory. As can be seen, executive functioning and rehearsal accounted for 15% of the total variance in IQ. By comparing the bottom-up analysis to the full top-down analysis, it is possible to determine where the variance accounted for by executive functioning and rehearsal in the latter model comes from in the former. Very short-term memory accounted for 14% in the

bottom-up but only 3% in the top-down analysis, and primary memory accounted for 10% in the bottom-up and 7% in the top-down analysis. Evidently, executive functioning and rehearsal operates on the earliest processes of very short-term memory and primary memory and appears unrelated to secondary memory and tertiary memory, suggesting that long-term memory is less strategy-driven than is short-term memory. (Alternatively, it could mean that there are no effective variables in the battery that represent strategy in long-term memory.)

Each of these models accounted for 86% of the variance in Full-Scale IQ because they all use the same set of variables. Which is best? From a purely parsimonious point of view, the bottom-up model is best because it accounts for the same amount of variance with fewer variables. It also suggests that more global processes, such as executive functioning and rehearsal, are derivative of differences in more basic processes. Even though the bottom-up model is most parsimonious, the top-down model seems preferable because it better characterizes the actual state of affairs as reflected by research findings with persons who have mental retardation. A large portion of the variance in memory performance is certainly due to differences in strategy. When strategies are reduced or eliminated, individual differences are reduced (Clark & Detlema, 1981). To lump strategic behavior in with very short-term memory and primary memory does not represent a large body of research findings concerning strategic behavior. The revised model model is shown in Figure 2. In this model short-term memory replaces primary memory and long-term memory replaces secondary memory and tertiary memory. Efficiency is included with stimulus coding, and the executive functioning of the revised model is equivalent to executive functioning and rehearsal.

What do the previous analyses reveal about the modal model and individual differences? Obviously, the outcome of hierarchical regression analysis is highly dependent

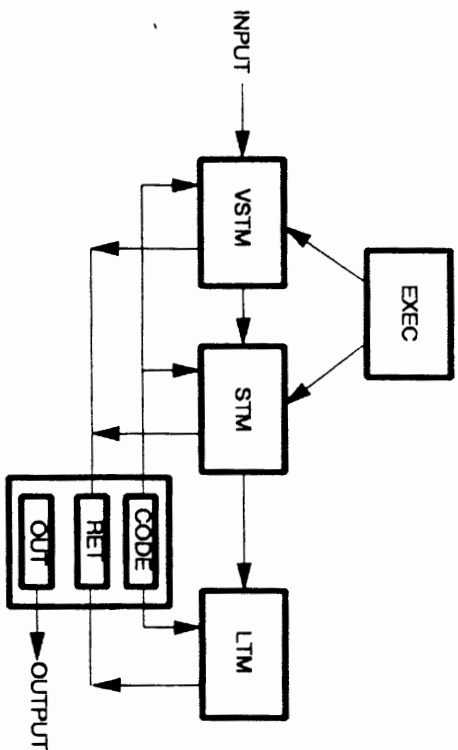


Figure 2. Revised modal model.

on the order in which variables are entered. Further, the way in which the composite variables were constructed and how parts of the system were defined also have an important impact on the outcome of these analyses. Despite these qualifications, there are conclusions that can be drawn that are consistent with other findings presented earlier. First, it is clear that no single process can account entirely for individual differences in intelligence. Each of the components used in these analyses made an independent contribution to explaining IQ. This could not occur if differences resulted from a single deficient process. Second, basic processes such as memory, encoding, and retrieval are important in explaining intelligence. These basic processes accounted for more of the variance than did more global processes. Third, more global processes are actually the result of differences in the more basic processes. Finally, the results support a slightly modified version of the modal model as being a not unreasonable framework for representing individual differences in intellectual func-

tioning. It should be possible to test this model using more sophisticated methods such as LISREL in future research. What has not been explained by these analyses is exactly how differences in intellectual ability arise. That will require greater sophistication in measurement than so far obtained.

Discriminant Analysis

As validation of the analysis described previously, the composite scores were entered into a discriminant analysis to determine whether measures from basic cognitive tasks could predict group membership. Not surprisingly, using the discriminant function, and the resulting classification was highly significant, $\chi^2(10) = 60.00, p < .001$. More interesting is the size of the within-groups pooled correlation of each variable with the discriminant function that gives an idea of the importance of each variable. The correlations were: primary memory, .66; tertiary memory, .61; executive functioning, .48; very

short-term memory, .41; stimulus coding, .38; secondary memory, .36; retrieval, .31; efficiency, .19; output, .19; and rehearsal, .17. As in the hierarchical regression analysis, the basic memory processes seem to be most closely associated with individual differences. When the composites were entered into a hierarchical regression analysis from the smallest to largest in the previous list, each composite, except for executive functioning, accounted for a significant amount of variance.

Other Differences Between Groups

Even a cursory inspection of Tables 3 through 11 shows that participants with mental retardation performed more variably than did college students. Frequently, the *SD* of a measure of participants with mental retardation was 4 to 5 times larger. In a very general way, this is consistent with Dettmann's (1987) suggestion that subjects with mental retardation have different arrays of deficits, depending on the cause of their mental retardation.

Another difference is that correlations of our measures with intelligence were often higher for participants with mental retardation than for college students. The average absolute value of the correlation coefficient for each of the 31 basic parameters with intelligence was .15, .40, and .56 for college student, mentally retarded, and combined groups, respectively, suggesting that the relation between intelligence and basic cognitive abilities is not uniform across the full range of ability. This finding has been confirmed by Dettmann and Daniel (1989) in the WISC-R and WAIS-R standardization data. The subscales of each of these tests correlate with each other about twice as high for low-IQ subjects as for high-IQ subjects.

The average correlation of basic cognitive parameters with intelligence for college students was .28 after correction for attenuation. It is interesting that when Sternberg and Sailer (1982) discussed the .30 barrier for

the correlation between basic cognitive task parameters and intelligence, their argument was based on studies done almost entirely with college students. The results obtained here suggest that if the full range of ability is employed, the average obtained correlation between intelligence and cognitive ability will be .37, which roughly confirms Sternberg and Sailer's observation. The important point is that research on intelligence that does not include persons with mental retardation presents a restricted picture of correlations in the population. For the purpose of generalization alone, future studies of individual differences in cognition should include a wider range of IQ and MA than has traditionally been used.

Prediction of IQ by Basic Tasks

In order to determine to what extent IQ was predictable from basic cognitive tasks, we selected nine variables and used them in a multiple regression analysis. To obtain the nine variables, we selected one variable from each task as the most theoretically significant. Each variable was selected because it was, in our judgment, the major variable of concern in previous research on the task under consideration. The nine variables used were: SPDT, SPDTALL, PREROR, LRTTRIAL, RLBIAS, STDDPM, TPMPRO, and RTMEAN. All variables were then entered into a multiple regression equation (SPSS Factor procedure).

For the combined groups, the multiple correlation was $R = .92$ (shrunken $R = .89$), which was statistically significantly different than zero, $F(9, 30) = 17.15, p < .01$. For the mentally retarded group alone, the multiple correlation was $R = .91, F(9, 10) = 5.01, p < .01$, shrunken $R = .66$. For the college students alone, the multiple correlation was $R = .76, F(9, 10) = 1.48, p < .05$, shrunken $R = .44$. Other methods for obtaining multiple correlations produced essentially identical results. The multiple correlation for college students was always lower than that for the mentally retarded group. The multiple correlation for

the combined groups ranged between approximately .75 and .92.

Because the mentally retarded and college student groups had a restricted range and the combined group had an extended range, we assume that the population value for the multiple correlation lies somewhere between the two values. As a very crude indicator of what the multiple R might be in the full sample, the average of the two groups was taken. The average shrunken R computed for the two groups separately was $.55 (.44 + .66)/2$. The shrunken R for both groups combined was .89. Therefore, we estimated that in a random sample from the general population, the obtained multiple correlation would be $.72 (.55 + .89)/2$. Because intelligence tests correlate with each other in the range of .70 to .80, this result suggests that basic cognitive tests correlate with an intelligence test as well as different intelligence tests correlate with each other. The basic cognitive tests included in this battery contain the same common sources of variance as are shared by different intelligence tests.

A strong word of caution is required at this point. Some would argue that multiple regression should never be conducted on a sample of 40 subjects when there are 30 possible variables that could be used in the regression equation. As the number of variables approaches the number of subjects, a perfect multiple correlation is expected. However, we reduced the number of measures to a theoretically important measure. In addition, the data for each measure are highly reliable. Nevertheless, the only way to be certain about these results is to replicate them in larger samples.

Another point concerning these multiple regression analyses needs to be made. We selected measures because they have been viewed by previous researchers as important, but more explicit process models are needed for each of the tasks used here. Further, lacking some more specific models, it is impossible to judge which measures should account for variance common to the

tasks. Development of such models could be preceded by simultaneous study of several tasks at once.

Principal Component Analysis

One possible explanation for the observation that basic cognitive tasks predict standard intelligence measures is that both contain a single, common source of variance, namely, general intelligence or g . A common estimate of g is the amount of variance accounted for by the unrotated first principal component. In a typical battery of intelligence tests (or subscales of a single test), the first principal component typically accounts for from 60% to 80% of the variance.

In order to estimate the amount of variance accounted for by the first principal component, we conducted a principal component analysis using the 31 variables listed in Table 1 on the mentally retarded and college student groups separately and for both groups combined. The unrotated first principal component accounted for 19%, 36%, and 48% of the variance for college student, mentally retarded, and both groups combined, respectively. None of these values fall within the range typically obtained for principal components analysis of batteries of intelligence tests.

The most direct interpretation of this finding is that parameters from this battery of basic cognitive tests have lower intercorrelations than do intelligence tests or subscales. Because the parameters from the basic cognitive tests combine to predict as much variance as is accounted for by the correlation between intelligence tests, it cannot be the case that all of the parameters contain g but simply have less of it. If all of the basic cognitive tasks were measuring the same thing, they would not combine to predict as much variance as they do. Therefore, it seems reasonable to conclude that our basic cognitive measures account for different sources of variance. Thus, both the multiple correlations of the basic parameters

with intelligence and the low amounts of variance accounted for by the unrotated first principal component support the contention that our measures tap least partially independent sources of variance.

The Modal Model

A major goal of this research was to test the modal model presented in Figure 1 to determine whether it was an adequate representation of individual differences. The most parsimonious result would be to find that one part of the system was severely impaired in comparison to all other parts. This was not the case. Nearly every basic cognitive parameter demonstrated differences between subjects with mental retardation and college students. The deficits were so pervasive and ubiquitous that it is not possible, with current methods, to localize a deficit to a single process.

Another possibility is that the pattern of correlations might reveal the source of a deficit. If, for example, correlations of parameters with intelligence were low for early parts of the system and high for later parts, it might be reasoned that later parts of the system were most important in determining intellectual deficits. The point at which the correlations changed from low to high might be implicated as the major source of intellectual differences. All high correlations later in the system might be produced by the earlier single deficit process. Unfortunately, no such pattern of correlations is discernable.

It would appear that the modal model presented here is not capable of characterizing the results obtained, at least in any way we have considered. It is, perhaps, unfair to expect a model that was developed to characterize general principles of information-processing to account for individual differences. The model did provide a useful heuristic for obtaining tasks whose parameters were capable of predicting scores on standardized intelligence tests, but it is less difficult to see how the relations among

variables obtained in this research could be predicted by the modal model. The difficulty with attempting to verify the modal model, or any other model, with the data presented here is that it is fairly obvious that the parts of the model have complex interrelations, and those relations are not easy to sort out. Though it is easy to find measures that reflect individual differences, it is a much more demanding task to specify the relation among those measures. However, that is what will be called for, and it will require much more carefully specified models than the one presented here.

What sort of model would be required to account for these results? The findings suggest a system composed of independent parts that have a complex interrelation (see Detterman, 1980, 1982, 1986, 1987). The findings that the unrotated first principal component accounted for a smaller portion of the variance than is typical of measures of intelligence and that the cognitive parameters could add together to predict standard measures of intelligence suggest that the system is composed of independent parts. The complex pattern of correlations suggests that the parts of the system are intricately intertwined.

The ideal way to determine exactly what kind of model best represents the data would be to explicitly fit models to the data using structural equation modeling, such as that employed in LISREL. The problem is that the sample size is far too small to allow this approach in the present data set even if the models existed. However, it is possible to determine whether a LISREL approach could be useful in future studies. If all of the measures from basic cognitive tasks are highly intercorrelated, then there should be a major single factor, and this single factor should account for most of the variance in IQ. That is, general intelligence and the general factor from cognitive tasks could be considered the same thing. On the other hand, if the modal model or something like it is a more appropriate representation of the data, then multiple factors extracted from the measures of

the basic cognitive tasks should all contribute to the prediction of intelligence.

In order to test this, several principal axis factor analyses with varying rotations were conducted using from 10 to 30 variables and extracting from .3 to .7 factors. Factor scores saved from these analyses were then used in a multiple regression to predict full-scale IQ. In all of the analyses, all factors produced regression equations that were significantly different than zero. Each factor contributed unique variance to the prediction of IQ. This finding indicated that basic cognitive tasks provide measures that are factually more distinct than are more complex measures such as subsets of an intelligence test. This means that the general goal of building a model similar to the modal model by specifying independent sources of variation is not an unreasonable one. (The ideas for these analyses were suggested by Lloyd Humphreys and Arthur Jensen, personal communications.)

Beyond this general description, it is not possible to describe what a modal capable of adequately accounting for individual differences would be like. The first task that must be accomplished before the model can be better specified is to determine what the independent parts of the model are. Parameters from the tasks used here account for as much variance in the WAIS-R as in other intelligence tests. Therefore, this battery of tasks must contain all of the major cognitive abilities that compose intelligence. Accounting for IQ with the smallest number of orthogonal variables would provide the ideal model.

Though this research did not support the modal model or any particular model as useful for characterizing individual differences in intelligence, it did accomplish one of our original goals. Our results strongly support the idea that basic cognitive abilities are predictive of intellectual functioning. Despite the small sample size and other methodological problems, the results obtained are completely and consistently in agreement with the notion that higher men-

tal processes are significantly dependent on basic cognitive processes. The only qualification to this statement is that the extent of the relation varies across the ability continuum. Because the results are based on a small number of subjects studied intensively, they are, of course, preliminary and should be interpreted cautiously until they are replicated with larger samples.

In conclusion, the results support the idea first suggested by Cattell (1883) and Cattell (1890) that basic cognitive abilities are predictive of intellectual functioning. Although the sample size was small and there were other methodological problems, the results show that higher mental processes are dependent on basic cognitive processes. Indeed, it is a striking testimony to the pervasiveness and magnitude of individual differences in intellectual ability that with only a moderate amount of attention to reliability, we were able to demonstrate statistically significant differences on nearly all of the measures tested with modest sample sizes.

There are several conclusions that can be drawn from this research. A number of these may be controversial, but we believe the data reported here support them.

1. A program of research in mental retardation can no longer be based on a single task if it is to make a theoretical contribution. Showing that persons with mental retardation perform poorly on one cognitive task can tell us little about the cause of mental retardation. The truth is that such persons perform poorly on all kinds of tasks. What is now required is an explanation of why they perform more poorly on some than on others. Speculating on the source of deficits is only useful if there is, or can be, a prediction about how that particular deficit will affect other measures of performance. The implication of deficit theories has been that the demonstrated deficit somehow caused all other processing deficits, but how the deficit caused them was seldom, if ever, exactly specified.
2. There is no doubt that intelligence

can be accounted for by basic experimental tasks. The remaining question is just how basic the basic tasks can be. The correlations found between tasks in this research suggest that it should be possible to obtain prior measures of cognitive processes than were used here. That means that even more basic tasks than were included in this study could be used to explain intelligence. A fundamental, and theoretically important, question is just how basic the tasks can be before they no longer explain intelligence. Some early theorists (e.g., Galton) suggested that intelligence was no more than differences in sensory and perceptual discrimination. Can tasks that are considered primarily sensory account for as much intelligence test variance as the basic cognitive tests used here? To my knowledge, this question has never been given a fair test.

3. Performance among mentally retarded groups does not simply represent performance of subjects without mental retardation with a reduced mean. There are numerous indicators that the performance of subjects with mental retardation is substantially, and perhaps qualitatively, different from that of college students. Among those differences are higher correlations in low-IQ groups, substantial differences in variance across groups, and differences in patterns of performance on the individual tasks. Given this wide range of differences, it is worth speculating about whether a single conceptualization can account for performance across the full range of intellectual ability. If the classic experiments of experimental psychology were repeated with subjects who have mental retardation, would the general laws still be the same? Given the results of this research, it would appear highly unlikely. Any theory of cognitive functioning will have to account for individual differences if it is to be considered complete. It may be the case that the organization of the mind varies systematically as a function of intellectual level.

4. The fact that the basic cognitive tasks used here have relatively low intercorrelations

as compared to standard intelligence tests suggests that they may be more useful for assessing the patterns of abilities. Although this has always been an ambition of the makers and users of intelligence tests, the high intercorrelations among subjects made them practically useless for assessing patterns of ability. A single score, the IQ, was the only practically useful information to be had from such tests.

5. The modal model is a reasonable representation of individual differences in intelligence, or at least probably as good as any other.

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COMMENTARIES ON DETTERMAN ET AL.

Is Less Really More? Using Microlevel Sensory and Cognitive Measures to Predict Macrolevel Cognitive Outcomes

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Detterman et al. (1992) have made more out of less than any other researchers in a long time. In managing to squeeze cogent results out of the performances of two groups of subjects whose scores comprise restricted ranges of variability, namely, 20 college students and 20 young adults with mental retardation, these researchers have provided what is possibly the most overdue assessment of the nature of mental retardation since Zigler proposed his two-group theory (see Zigler, 1988). In short, they have suggested that the cognitive performance of young adults with mental retardation is not simply quantitatively lower than that of adults without mental retardation, but also qualitatively different. If they are correct, then the implications for further research and intervention would be great, indeed.

In support of the claim of qualitative differences, Detterman and his colleagues (1992) reported a number of findings, including greater variability among adults with mental retardation and different patterns of performance on a set of microlevel cognitive tasks. This should not surprise anyone who is familiar with individuals in the IQ range studied by these investigators, as persons

with IQs in the 40s and 50s seem quite unlike those with IQs in the 70s. Surprise or no surprise, it is nice to have support for what our experience so amply suggests.

In addition to the just mentioned findings, Detterman et al. (1992) reported a larger magnitude of *g* among adults with mental retardation. It is this last finding that I shall dwell on because it contains the most startling implications for the larger field of psychometrics as well as for those involved in screening and intervention.

What does it mean to characterize the cognitive operations of a group of individuals as being qualitatively different from those of another group? One thing that we learn from Detterman et al.'s analysis is that this means that young adults with mental retardation are less differentiated than are college students; that is, young adults with mental retardation are the only group who conform to classical psychometric expectations about *g* (though even their first principal component is somewhat lower in magnitude than what is customarily reported to be found with diverse samples of subjects). Their test batteries consistently yielded higher magnitudes of *g* than did college students' batteries, sometimes two or three times higher. This means that their test scores are more tightly intercorrelated, which, in turn, implies that the size of their first principal component is larger. Although the first principal component accounted for only 19% of college students' test score variance, it accounted for 36% of the variance for adults

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with mental retardation. One wonders whether this finding will add fuel to the debate over the usefulness of the concept *mental age* (MA), because chronologically younger subjects who do not have mental retardation are known to exhibit less differentiated performances than do adults without mental retardation (Sternberg & Powell, 1983).

For many years, the assumption among researchers and policy makers has been that saturated tests, of which the intelligence test is the best known, are valuable for screening and diagnosis. Although no one claims that such tests are perfect predictors of school, social, or occupational success, they are better than any alternative predictors that have been studied (Ceci, 1991). However, Detemman et al. (1992) have just thrown a spanner into this popular wisdom by showing that the magnitude of g , when it is derived from a sample that includes adults with low IQs, is disproportionately large as a result of the higher degree of intercorrelatedness of their lower IQs. The implication of this finding is that when g is derived solely from subjects in the average and above-average range of IQs, its magnitude would be far smaller than what psychometric researchers usually find when they derive g from a sample that spans the entire range of IQs; a conclusion that Detemman and Daniel (1989) have supported elsewhere. Certainly, the college-age subjects in their 1989 study were considerably more differentiated in their performances than could be captured by the first principal component, a surrogate for g .

In my opinion, this finding implies that reliance on g -based measures for screening and diagnosis is likely to mislead the tester into believing those tested were less differentiated than may be the case, at least for those with average to above-average scores (Ceci, 1990a). Just how many individuals will be mistakenly programmed by educators and trainers is not clear, perhaps only those with IQs one or more standard deviations above the mean are as differentiated as

Detemman et al.'s (1992) college subjects. Or perhaps this applies to all individuals with IQs above those of subjects with mental retardation in the Detemman et al. study. It is an empirical question that deserves to be answered because of its implications for screening and diagnosis. The implications for intervention also seem clear: Given the pervasive deficits of the subjects with mental retardation, single-approach interventions may produce better results than would be the case for the more differentiated higher-IQ subjects, who would require a more modular approach that is aimed at specific aptitudes. Detemman et al. are to be thanked for opening up this issue to empirical examination and debate, and I would strongly encourage them to pursue this topic to its ultimate policy implications.

Performance of the adults with mental retardation was not simply a miniature version of that of adults without mental retardation; that is, it is not accurate to characterize their profiles as similar to those of adults without mental retardation but with a lower mean. A number of variables were predictive of one group's performance but not the other's. For example, the time to decide which of a set of stimuli actually appeared on the screen was predictive of IQs of adults with mental retardation, $r = .70$, but not IQs of adults without mental retardation, $r = .02$. In general, adults with mental retardation were more impaired by increases in task complexity than were those without mental retardation, and even though motor processing was slower in the retarded group, it was not as strong a predictor of their slower performance as were *decision-speed* measures. Thus, adults with and without mental retardation are apparently qualitatively different in their modes of processing. But why?

Caveat Lector

The present research needs to be refined, replicated, and extended before it can be considered scientifically robust, a point

acknowledged by the authors. Three areas in particular need of attention are: (a) It is critical that a stratified cross-section of the population be assessed to avoid over- and undersampling that is inherent in an extreme-groups design such as the present one. Extreme groups lead to inflation of not just the correlations but also the discriminant function. (b) The basic measures should be checked to ensure that they are not achieving their discriminability because of factors unrelated to the logic of the tasks themselves. For example, on tasks such as the partial tachistoscopic report, it appears that adults with mental retardation did not understand the instructions. If this is true, then what discriminates them from college students on this task may be unrelated to what this task is presumed to measure. Finally, (c) the testing environment needs to be made as comparable as possible for all groups (e.g., crowding college subjects with an experimenter in the 1.5 m room for the same length of time as was used for adults with mental retardation). All of these points address the *possibility*—indeed the likelihood—that many things were going on in these tasks, not all of which were cognitive and/or being studied. Group differences in the use of computers, video games, taking speeded tests, sitting still for prolonged periods of time, and confidence may result in differences between the two groups that are only remotely cognitive. If this assertion is correct, then this could shed light on the fact that measures concerned with speed or latency were the *best* discriminating between retarded and nonretarded groups, while simple accuracy measures were the most. Moreover, although not mandatory for the purposes of this research, it would be valuable if the present tasks were contextualized; that is, it would tell us a lot about the nature of the group differences as well as subgroup and individual differences if the tasks were presented in more settings than only the disembodied computer displays used here. Perhaps video games requiring shorter peri-

ods of attention would be a good candidate. A wise person once remarked that nothing is more practical than a good theory or model in the future it would be valuable to test alternatives to the modal model, which is a sensible first effort, but probably too coarse to describe individual differences in the flow of information between various structures. In particular, there is undoubtedly greater "borrowing" between early (e.g., very short-term memory) and later (e.g., tertiary memory) structures than could be assessed with the present tasks. It is not only that the efficiency of the early structures defines the efficiency of the later structures, but the reverse seems just as likely, with early processing being influenced by the nature of the mental representation.

Finally, the search for the gem of intellectual eminence has a long history, paralleling the history of scientific psychology (Ceci, 1994b). We need to resist the temptation, until more evidence is available, to assume that intelligence is dependent on basic processes. It is not only difficult to believe that the sum total of what we regard as "intelligence" is captured by intelligence tests (an implication of the authors' conclusion), but it is hard to imagine that basic perceptual and sensory measures underpin the totality of what is measured by intelligence tests, notwithstanding the .86 hierarchical multiple regression. Surely, basic processes contribute only a small part of the variance found on tasks of analogical reasoning, spatial cognition, and other abilities. Correcting range-extended correlations cannot remedy the problem inherent in the correlations themselves—in this instance the possibility that scores of the subjects with mental retardation may have reflected the operation of variables that were not under examination in this study. After all, such persons perform more poorly than do college students on a host of tasks that have little in common with the basic cognitive measures employed here; for example, they do not tap their fingers to rhythm as well, and they curl their toes more

slowly in response to foot tickling. That they are deficient on such tasks may or may not reflect differences in basic cognitive processes. This logic applies to the tasks used in the Detemman et al. (1992) study. Simply put, it is valuable to understand exactly what factors are being tapped by the tasks before we give in to the temptation of believing that just because performance of individuals with mental retardation is inferior to that of college students on certain tasks, it is the result of the cognitive mechanisms that the tasks were designed to reflect.

Last this be taken as a criticism of what Detemman et al. (1992) have accomplished in this research. Let me hasten to add what I have yet to state explicitly: I am most impressed by their journey to make so much out of so little. Their work should provide the grist for a rich research program for many years to come, and one can only hope that their efforts will be followed by researchers who are as careful and creative as they are.

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Relation Between Information-Processing Time and Right/Wrong Responses

The study by Detemman et al. (1992) strongly reinforces the findings of many other recent investigators showing that a large part of the variance in general mental ability as measured by conventional psychometric tests can be accounted for by individual differences in the speed and efficiency of a number of elementary information processes, as distinct from specific knowledge and skills. As I have explicated in detail

elsewhere (Jensen, in press), the general factor, g , common to all cognitive tasks, especially psychometric tests of intelligence, shows a much stronger relation to performance on elementary cognitive tasks than do any other factors in mental tests. It is as if the general factor, g , is a distillate from subjects' right/wrong responses to a large number of test items, reflecting only the common element among a wide variety of items that involve disparate bits of knowledge and specific acquired skills, and this common element, or g , is really the speed and efficiency of processing information, that is, information in the generic sense.

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Processing Time

The data of Detemman et al. (1992) also strengthen the hypothesis that a number of independent elementary processes enter into g (Kranzler & Jensen, 1991). This hypothesis is the essential condition for Detemman et al.'s conjecture that persons with mental retardation have a deficiency in one or more of the different basic information processes.

However, there is no reason to believe that the deficiency should occur in one and the same process for all persons with mental retardation. Yet Detemman et al. stated: "The deficits were so pervasive and ubiquitous that it is not possible to localize a deficit to a single process" (p. 276). The authors are, of course, referring to the *mean* of their mentally retarded group as compared to the college group. However, there could well be a large overall *mean* difference between the two groups on each of the basic processing variables even if each member of the retarded group were deficient in only a single one of the several processes. One could never tell by simply looking at means, assuming that any one of the relatively independent basic processes is a critical constituent for a normal level of g , critical in the sense that, for example, any one of the four legs of a table is critical for its stability. Little if any attention is paid here to the fact that the coefficient of variation (CV = standard deviation/mean) of the response latencies on nearly all of the elementary cognitive tasks is much larger for the retarded group than for the college group; that is, on any particular task, there is very much greater variation among the persons with mental retardation than among the college students. This is precisely what one should expect if only *some*, but not all, of the persons in the retarded group were deficient on any particular processing measure, whereas none of the college group were deficient on any of them. This possibility, which was not really considered by Detemman et al. (1992), deserves closer examination. If no reliable overlap could be found between the distributions of the two groups on any of the elementary cognitive task variables, it would suggest that mental retardation in every subject involves a deficiency in each and every one of the basic cognitive processes measured in this study.

The issue I especially wish to amplify, however, concerns the comment by Detemman et al. (1992) that the mean differences between the retarded and college groups are generally larger (in standard score units) on variables that measure correct responding than on variables that measure response latency or speed. This statement may suggest to some readers that response variables that can be scored as right or wrong are in some way essentially different from variables measured as response latency, or reaction time (RT). It is true that variables scored right or wrong are generally more highly correlated with g and, hence, are more discriminating between retarded and nonretarded groups than are variables measured as RT (or its reciprocal, speed). However, I would suggest that the two types of variables are two aspects of one and the same underlying continuum of speed and efficiency of information-processing. (Efficiency is reflected by the degree of the person's trial-to-trial consistency, or intrasubject variability, in RTs.)

For a given person, the difficulty (i.e., probability of incorrect response) of any particular test item is a function of either one or a combination of two things: whether or not the item's information content is available in the person's long-term memory and the complexity of the item's information-processing demands. When variance in item difficulty due to the content demands is minimized, as is typically the case for tasks such as those used by Detemman et al., then most of the variance in item difficulty will be due to the complexity of the processing demands. The greater the complexity, the more mental manipulations or transformations of the stimulus input are necessary in order to arrive at the correct response. Hence, the probability of a correct response is a

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function of (a) speed and efficiency of processing and (b) the rate of decay of information in working memory (the active aspect of short-term memory). Arriving at the correct response is a race between a and b. When an essential element of information or a transformation of it is lost from working memory before all of the processing required for a correct response has been completed, there is a "breakdown" in processing, and a response error is likely.

That response latency and item difficulty reflect one and the same process is shown by giving the *same-test items* to young children and to university students. In one study (Jensen, Larson, & Paul, 1988), items of a semantic verification test were given to elementary school children (Grade 3) as an untimed paper-and-pencil test. The test items were sufficiently complex to elicit both right and wrong responses, making it possible to rank order the items in terms of their average difficulty. The very same items were given to university students in the form of an RT test; they were so easy for university students that they were almost no errors, and reliable individual differences could be measured only in terms of response latencies. The fact that the rank order of the university students'

mean response latencies is highly similar to the rank order of the children's mean errors on the same set of items means that the processes that determine item difficulty also determine response latency. The latencies of the responses that occur closest to the threshold of a "breakdown" in information-processing (i.e., the point at which response errors are first likely to occur) are the most highly correlated (negatively) with psychometric g .

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more comprehensive studies such as this one as opposed to the narrow and sometimes myopic investigations characterizing so much research in psychology.

Given the energy that went into the work, it is unfortunate that none of the conclusions follow from the data. The conclusions are not necessarily incorrect, but they are not justified by the empirical results that were obtained.

What went wrong? Several things.

1. None of the correlations involving parameters for the college students versus the students with mental retardation can be taken at face value, and most of them are

uninterpretable. The variances of parameters in the two groups are severely divergent. I am not talking about the minor deviations from homogeneity of variance that often characterize data and against which statisticians are generally robust. The differences here are whopping. For example, in Table 3, the first comparative table, there are variance differences (squares of given standard deviations [SDs]) representing factors of 5 (LRRIAM), 360 (LRMPTTR), 3 (LRPERCORR), 94 (LRBIAS), and 500 (LRNULLRESP), to give an idea of the range. These extraordinary differences make parametric statistical tests of no value and vitiate the importance of the authors' finding that correlations are higher for the students with mental retardation than for the college students. These differences pervade other tasks as well, not just the learning task of Table 3.

2. Conclusions about the students with mental retardation and college students combined are also compromised. Researchers are sometimes criticized for using college-student samples because the typical resultant restriction of range in intelligence levels can depress correlations. However, at least such tests are conservative. The normal variance of the scale used, the Wechsler Adult Intelligence Scale (Full-Scale IQ), is 225 (15²). In the population used in this study, the variance was 650, almost three times the normal variance. This almost three-fold increase in variance will of course raise correlations for the combined sample well beyond normal.

3. None of the conclusions about causes of mental retardation can be taken at face value, as the data are uninformative with regard to such causes. There are four reasons why the data are uninformative. First, in order to draw the conclusion that X and not Y causes mental retardation, one needs a pattern of convergent-discriminant validity—some measures relating to the target phenomenon (in this case, mental retardation), others not. As the authors honestly admitted, they obtained no such pattern. They achieved convergent but not discriminant validation. However, when everything relates to the

target phenomenon, one simply cannot say what does and does not cause the phenomenon. Further, the attempts to interpret sizes of correlations are very hazardous, given the wide range of variances for the parameter values. The data are simply not definitive.

Second, the authors are in an uncomfortable position, in which "each of their models accounted for 86% of the variance in Full-Scale IQ because they all use the same set of variables" (p. 278). The authors then ask which model is best. This is stranger than the "strange situation" of developmental psychology. Clearly, there is no good way of distinguishing the models. The authors noted that one model is more parsimonious. However, instead of then choosing this model on grounds of parsimony (which are weak in any case), they choose the alternative "because it better characterizes the actual state of affairs as reflected by research findings" (p. 278). This disregard of their own data in favor of prior ideology runs throughout the paper.

Third, one cannot infer causation from correlation. There was no causal modeling in this article, and hence the various causal attributions are unwarranted. Readers cannot conclude that the component differences cause retardation. There may be some other causal variable or variables producing both mental retardation and increased latencies and error rates.

Fourth, correlations may be higher for the students with mental retardation because some of them simply did not understand the task. This lack of comprehension would be consistent with the extremely high variances for some of the parameters. If this were true, an examination of scatter plots (not shown in the article) would reveal that a few subjects are accounting for most of the higher correlation, as correlations are very sensitive to extreme cases.

4. Conclusions from the principal components analysis are dubious. A standard rule of thumb in principal-components and factor analysis is that there be 10 times as

A for Effort, But . . .

Delleman et al. (1992) represents a tremendous effort by a major investigator in the field of mental retardation and his colleagues. Through the model presented, Delleman et al. seek to understand the information-processing bases of mental retardation. They deserve praise for the scope and ambitiousness of their study. We need

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Mopping Up: The Relation Between Cognitive Processes and Intelligence

I thank Ceci (1992), Jensen (1992), and Sternberg (1992) for their careful reading of our paper (Dettelman, Mayer, Caruso, Legree, Connors, & Taylor, 1992). Their thoughtful comments raised many important points. Unfortunately, I cannot respond in the detail I would like to all of the points raised. Some deserve a book of their own. I will touch on points that I think need additional attention or clarification. I will consider the papers alphabetically by author.

Ceci (1992) made several significant points that I endorse. The finding in our study that the correlation structure differed from low- to high-IQ subjects has implications for assessment and intervention, as he pointed out. It is even more important to understand why such differences occur. Understanding correlation differences could give a clearer understanding of mental retardation and intelligence.

Another point made by Ceci (1992) that should be emphasized is that persons with

many subjects as variables. This is only a guideline, and it is frequently violated. But it gives us a standard. In this study, principal-components analysis was done on the entire sample of 40 subjects using 31 variables, a ratio of about 1.3:1. Worse, such analysis was also done for the separate groups (20 college students, 20 students with mental retardation), yielding a ratio of about 0.65:1. This is less than 1:1 ratio is very unusual. Under these circumstances, one can interpret the results only with extreme caution.

Equally important, some of the variables entered into the principal-components analysis are experimentally or statistically independent, which creates artifactual correlations and distorts the factor structure. Consider just one example: STDDPM (14), the mean decision time for positive trials, and STDDPS (22), the slope of decision time by set size for positive trials. Mean and slope of the same stimulus set for the same subjects cannot be independent. In Table 10, the correlation is given as $-.84$. The inclusion of spurious correlations such as this one vitiates interpretation of results.

Further compromising interpretations of the principal-components analysis are the low reliabilities of some of the variables. Because reliabilities are given only for the combined samples, the tabulated reliabilities (Table 3) are probably substantially higher than for the two groups individually. Some reliabilities are not given at all, but even for those given, some are very low (e.g., .19 for SDDTINT, .04 for SDPOSS/OPE, and .00 for TPIDSCRO), which lowers correlation and thus produces smaller principal components.

5. *The conclusion that cognitive tests correlate as well with an intelligence test as intelligence tests correlate with each other is*

misleading. This conclusion, which defies hundreds of past studies showing lower correlations of cognitive tests with psychometric tests than of psychometric tests with themselves, is based on a spurious comparison. The authors are comparing a multiple correlation based on *nine* independent variables to a simple correlation based on *one* variable. It gives a tremendous advantage to the cognitive tests. With enough such tests, one could probably reach a multiple *R* approaching 1.00, but so what? One cannot compare a nine-variable multiple *R* to a one-variable simple *R* and conclude that if they are about the same, the two kinds of variables are comparable. Even worse, there were only 40 subjects in the entire sample, and the starting number of variables was 30. It is no surprise that the multiple *R* was high.

The most informative statement in the article, in a sense, is "It would appear that the modal model presented here is not capable of characterizing the results obtained, at least in any way we have considered" (Dettelman et al., 1992, p. 282). The authors are correct. Despite their efforts, no conclusions about the modal model can be drawn from their data. In fact, though there are many conclusions in this paper, careful analysis reveals serious flaws. The intentions of the authors were good, but the study did not live up to their intentions.

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The point I like best of all in Ceci's (1992) commentary will probably surprise him. It is the possibility he raised that many things are going on in these apparently simple cognitive tasks. When we began this study, it was our idea to use simple cognitive tasks to reduce the many influences often present in more complicated tests. Ebbinghaus had the same idea when he invented nonsense syllables. Both ideas are wrong because they are simplistic. Human intelligence is an integral system. If there is one lesson to be learned from the present study, it is that it makes little sense to study parts of a complex system in isolation. We need to understand the system as a whole. What we call "simple cognitive tasks" are not simple. They involve all the things Ceci mentioned and more. They reflect the operation of an integrated system.

Ceci (1992) is also correct in his assessment of the modal model. It may be the best model currently available, as we concluded.

However, it is too crude to characterize the complex interactions that occur. We need better models, (finding better models requires) defining the parts of the system precisely and understanding how they interact. This understanding will come from studies investigating several cognitive tasks simultaneously.

I have one point of disagreement with Ceci (1992). He suggested that we should resist the temptation to conclude that intelligence is dependent on basic sensory and perceptual processes. He is correct that intelligence is not completely dependent on these basic processes. For those of us who work with persons who have mental retardation, though, it is hard to understand that some people do not believe there is a relation between the basic processes of the brain and intelligent behavior. We see what damage to the brain can do to behavior. It is not clear how much sensory, perceptual, and other cognitive processes will account for IQ, but it will definitely be something. At least, that is what the results of the present study suggest. So does my experience with persons who have mental retardation. How much such processes account for IQ is an important question, and one that may be easier to answer than many we ask about human intelligence.

Jensen's (1992) comments are almost entirely consistent with my point of view. He made some important points. Perhaps the most important is the mounting evidence for the hypothesis (Detterman, 1982, 1986) that *g* is composed of a number of independent processes. Our study supports that hypothesis. Not all measures of cognitive ability were uniformly depressed in persons with mental retardation. If general intelligence resulted from a single process, all measures related to IQ should have been uniformly depressed.

Kranzler and Jensen's (1991) results support the same point. They found that factors obtained from reaction time (RT) tasks are not identical to the factors obtained from psychometric tasks; *g* is different for the

RT tasks than for the psychometric tests. Kranzler and Jensen concluded that *g* comprises a number of independent processes.

Another important point made by Jensen (1992) is that sources of cognitive deficit could be different for persons with mental retardation due to various causes. I have discussed this possibility elsewhere (Detterman, 1987). Greater variability would result from multiple deficits, as Jensen pointed out. However, there could be other reasons for the increased variability, a hallmark of behavior of persons with mental retardation. Increased variability might be associated with a less efficiently operating system, even if the system is made inefficient by a single, universal deficit.

Jensen is also right that simply looking at means will not show whether different subjects have different deficits. He suggested that if there is no overlap between subjects who have mental retardation and college students, there is a deficiency in all cognitive processes measured. That may not be the case. Jensen's conclusion assumes that each measure is independent of the others, which is unlikely. A single deficit in a complex system could impair the operation of the entire system.

How will we find the processes displaying primary deficits? How will we determine whether low-IQ subjects can be characterized by a few deficits common to all subjects? One way would be to compare persons with mental retardation in specific diagnostic categories. For example, do individuals with Down syndrome show the same pattern of cognitive deficit as do other persons with mental retardation? It is likely that all persons with Down syndrome will display the same deficit because their retardation results from a common cause. It is not clear whether they will display the same pattern of cognitive behavior as do persons with, for example, Fragile X syndrome.

A second way of getting a clearer idea of the cognitive processes most affected in persons with mental retardation is to clarify the cognitive tasks measuring those pro-

cesses. By "clarify," I mean two things: First, cognitive tasks must be better understood. We have only a rudimentary idea of what happens when a person does, for example, an RT task. Second, tasks must be developed that measure the processes we intend them to measure as purely as possible. Though we made a real effort to reduce the correlation between tasks in our study, correlations still were found. It will not be easy, and may be impossible, to find measures uncorrelated with each other. To the extent that correlations between tasks can be reduced, better measures of mental processes will result. Uncorrelated tasks will also provide a better understanding of the function of mental processes.

The only point I might disagree with Jensen (1992) about is that latency and errors represent two sides of the same coin. He presented evidence suggesting they are. In some tasks, though, latency and errors reflect different processes. The tachistoscopic task where subjects decided whether two stimuli were the same or different is one example. Response latency has never been related substantially to intelligence or to the perceptual threshold being measured. There are other examples such as this (see later additional discussion). Whether response latency and errors reflect the same processes seems to me to be an open question. The answer may be different for each task.

Sternberg's (1992) comments are particularly gratifying. In some circles, when an argument is not going the right way, the offended person reaches for a concealed weapon. In other circles, they quote scripture. In the social sciences, we are much more civilized. We go for the statistics.

We were well aware of the issues raised by Sternberg (1992) when we designed and conducted our study. We acknowledged these problems in the paper. Our approach was like the one used by researchers in the areas of sensation and perception. They study a small number of subjects intensively. Most of the conclusions we drew were obvious from inspecting the data. No statistics

were needed to support our major findings. It should (or may not) make Sternberg happy to know that since completing this study, we have replicated the results. In several studies we gave a similar battery to 149 high school students whose IQs were almost perfectly normally distributed and to over 1,000 Air Force enlistees. Results of these later studies supported all of the major conclusions reached in the present study.

What caused Sternberg (1992) to go statistically critical and become Ballistic Bob? My guess is that he has difficulty agreeing with the conclusion reached in this study that basic perceptual and cognitive processes predict human intelligence. Sternberg and Salter (1982) argued that cognitive tasks always correlate less than .30 with intelligence. They talked about a .30 barrier on such correlations. This correlation ceiling implied that basic cognitive processes were unimportant in intelligence because each accounted for little variance in IQ.

I would like to be able to address each point raised by Sternberg in full detail. I am afraid that would test the reader's patience and the *Journals'* page limits. Instead, I will address what I consider to be the most serious errors Sternberg made. I have selected these mistakes because they are criticisms often raised by researchers who do not work with persons who have mental retardation.

Sternberg's (1992) first major point raised concerns about the difference in variability between subjects with mental retardation and college students. Sternberg may not know that differences in variability are unavoidable in comparisons between persons with and without mental retardation. The pervasive difference in variability is a major puzzle of low IQ, as Ceci (1992) and Jensen (1992) pointed out. If we abided by the strict statistical criteria of equal variance across groups, we would never do a study comparing subjects who have mental retardation with anyone. Nearly every study published in this *Journal* for the last 50 years would be unacceptable by Sternberg's standards. For-