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Age, Speed of Information Processing, Recall, and Fluid Intelligence

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On three occasions, 63 adults, ranging in age from 26 to 80 years, all in good health, were tested with three speed of information-processing paradigms (the Sternberg, the Posner, and the Hick), two long-term free-recall tasks, and, as a measure of fluid intelligence, the Raven Advanced Progressive Matrices (RAPM) test. Whereas within-condition latencies for the three of the information-processing tasks and recall scores were found to be reliable and consistently correlated with age and RAPM, individual differences in within-condition accuracies and between-condition slopes produced by the three information-processing tasks were found to be unstable over time and unrelated to age and RAPM. As suggested by Salthouse (1985), a large portion of the age-related differences in fluid intelligence was found to be accounted for by age-related declines in a general latency factor (cognitive speed). Furthermore, in agreement with Salthouse, this general latency factor appeared to reflect more than what can be accounted for by the simplest of information-processing tasks (simple reaction time). Finally, given that free recall had a substantial independent effect on RAPM when age and latency were held constant, the results called into question the assumption that cognitive speed can account for all individual differences in IQ.

Over the past 2 decades, researchers have reported small to moderate negative correlations between reaction time (RT) on elementary information-processing tasks and measures of psychometric intelligence (IQ); (cf. Vernon, 1987). Because these RT tasks have been considered devoid of content and relatively free of influence from academic experience, many researchers exploring the connection between RT and IQ have concluded that RT largely reflects a property of the neural substrate: transmission time, conduction time, or neural efficiency. Put simply, mental speed underlies intelligence. On the assumption that IQ is the effect and not the cause of its biological underpinnings, these investigators have argued that variability in IQ is the consequence of individual differences in one or more of these neural attributes (Eysenck, 1987; Jensen, 1987a; Vernon, 1987). Although concurring that RT is related to IQ, others have questioned the simplicity of the mental speed explanation and have contended that higher order

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cognitive processes may play a role in the RT–IQ association (Bors, MacLeod, & Forrin, 1993; Longstreth, 1984).

One of the information-processing paradigms first studied from the standpoint of individual differences in mental abilities was Sternberg's (1966) short-term recognition memory (STM) task. Here, subjects are presented with a list of one to seven digits or letters (the memory set). After each list, the subject is asked to determine, as quickly as possible, whether a probe item was present in the memory set. Response latencies have invariably been found to be an increasing linear function of memory set size. The slope of that function has been considered to be the time a subject requires to compare the probe with a single item in STM. The relation between comparison time as an index of mental speed and IQ has been equivocal. Although Hunt, Frost, and Lunneborg (1973) reported high-verbal subjects to have shallower slopes than low-verbal subjects, Chiang and Atkinson (1976) subsequently failed to find a relation between slope and either the verbal or the mathematical portions of the Scholastic Aptitude Test. More recently, however, Miller and Vernon (1992) and Roznowski (1993) reported weak correlations between slope of the RT set-size function and standardized aptitude tests. Finally, although the relation between IQ and the slope from the Sternberg task has been inconsistent, Jensen (1987b) reported a multiple correlation of .496 (.918 when based on disattenuated zero-order *r*s) when the slopes from the Sternberg and two other speed of information-processing tasks were used as combined predictors.

Several other information-processing paradigms have been explored with respect to their association with IQ (cf. Eysenck, 1987). The Posner same–different task (Posner, Boies, Eichelman, & Taylor, 1969) has been one of the paradigms most consistently associated with IQ. In the typical same–different experiment, two letters are simultaneously presented to the subject. The subject is instructed to indicate as quickly as possible whether or not the two letters are the same or different. In the name-identity (NI) condition, the subjects are told that the letters are to be considered the same if they have the same name (e.g., *A* and *a*). In the physical-identity (PI) condition, subjects are told that the letters are to be considered the same only if they are physical duplicates (e.g., *a* and *a*). NI latencies are characteristically longer than PI latencies (Posner et al., 1969). The difference in NI–PI, presumably the time needed by a subject to access overlearned information stored in long-term memory, has been found to be negatively correlated with various measures of intelligence (Goldberg, Schwartz, & Stewart, 1977; Hunt, 1977; Hunt et al., 1973; Hunt, Lunneborg, & Lewis, 1975; Keating & Bobbitt, 1978).

The predominant paradigm for investigating the link between RT and IQ was developed by Jensen (Jensen & Munro, 1979) and is based on Hick's law (Hick, 1952) that RT increases linearly as a function of the $\log_2$ of the number of possible stimuli (stimulus uncertainty in bits). By varying stimulus uncertainty, Jensen's procedure was designed to estimate the time it takes a subject to process a single bit of information, a parameter reflected in the slope of the RT-uncertainty function. Whereas the RTs of subjects within the individual bit conditions have regularly been found to correlate negatively with IQ, the correlations between slope and IQ, contrary to what one might expect, have been weaker and less dependable (Jensen, 1987a). Indeed, some studies have reported no association between slope and IQ (e.g., Barrett, Eysenck, & Lucking, 1986).

As seen in the earlier two examples, in most speed of information-processing paradigms, change in RT across conditions (slope) is considered the variable of greatest theoretical interest. This is because slope can be viewed as a relatively pure measure of the speed of decision processes in that, conceptually, it is free of individual differences in those sensory and motor processes that are constant components of all individual condition latencies.

As pointed out by Nettelbeck and Rabbitt (1992), although the reliability of psychometric tests of intelligence has been evaluated thoroughly, the same has not been true for RT measures in information-processing paradigms. Carlson and Widaman (1987) suggested that most researchers investigating information-processing speed and IQ simply have assumed that both these measures reflect enduring traits without the requisite evidence that mental speed is stable over time. Paradigms with weak test–retest reliability will be of little utility in the attempt to link mental speed to psychometric intelligence.

Reports concerning the test–retest stability for comparison time in the Sternberg task have been inconsistent. After testing subjects on 3 consecutive days, Chiang and Atkinson (1976) found correlations of .28 (Day 1 and Day 2) and .78 (Day 2 and Day 3). Similarly, Jensen (1987b) reported a .75 correlation across two occasions. Although Roznowski and Smith (1993) found that subjects' median RTs within individual memory-set sizes were moderately stable for both digits and letters over the course of a week, they found the between-occasion correlations for comparison time to be only .05 (digits) and .33 (letters). In choice RT tasks, although RTs have been shown repeatedly to have high internal consistency (Jensen, 1987a), the test–retest stability of the slope of RT across the bit conditions has received less attention. In the only relevant study of which we are aware, Jensen (1987b) reported a .555 Spearman–Brown Boosted test–retest reliability coefficient.

Furthermore, as observed by Nettelbeck and Rabbitt (1992), little has been done to assess the interrelations among the measures of speed of information processing across various tasks. Rectifying this lack is one goal of this project. If they all are measures of a single underlying factor, such as mental speed, then we reasonably could assume that there would be substantial positive correlations among them. This study affords the opportunity to assess the temporal stability of RT in three speed of information-processing paradigms (the Sternberg, the Posner, and the Hick) as well their interrelations.

IQ has been much studied in the context of adult development and aging. Both cross-sectional and longitudinal studies have found age-related declines in cognitive functions presumed to be associated with fluid intelligence (Horn & Cattell, 1967; Salthouse, 1982, 1991, 1993, 1994). This has been particularly the case for tests such as the Raven Progressive Matrices (cf. Salthouse, 1992). Memory, especially free recall, has also shown age-related differences and declines (Poon, 1985). There is some evidence that this decline in free-recall performance does not reflect a reduction in crystallized general abilities. For example, Craik, Byrd, and Swanson (1987) found that, even when the groups were matched for verbal IQ and years of education, young adults performed significantly better than did older adults on free-recall tasks.

Older subjects have also been reported to have longer latencies on various information-processing tasks than do younger subjects (cf. Salthouse, 1985). Comparison time has often been found to be positively correlated with age (Anders, Fozzard, & Lillyquist, 1972; Strayer, Wickens, & Braune, 1987). Characteristically, older adults are also slower than their younger counterparts on simple RT tasks (Borkan & Norris, 1980; Salthouse, 1985), and the same is true of performance on choice RT tasks (Strayer et al., 1987). The difference does not appear to be a consequence of lack of improvement with practice for older subjects. Typically, there are no Age × Practice interactions; the rate at which older subjects improve usually is no different from that of younger subjects (Madden & Nebes, 1980; Salthouse & Somberg, 1982).

Age-related declines in speed of information processing have commonly been linked to age differences in higher cognitive abilities, such as memory functions and fluid intelligence. For example, Rabbitt (1990) contended that psychometric intelligence accounts for all of the slowing of information-processing rate associated with normal aging. Reversing the coin, Salthouse (1985) postulated that a reduction in speed of information processing is primarily responsible for age-related differences and declines in cognitive activities. He suggested that once information-processing speed has been partialled out, the correlation between age and IQ should vanish. He also predicted that, on the other hand, partialling out age should have little effect on the correlation between information-processing speed and IQ. Data reported by Nettelbeck and Rabbitt (1992) offer some support for Salthouse's predictions. They found that information-processing speed was a major factor in age-related declines in cognitive abilities. With respect to intermediate-term learning and retention, however, they discovered that age made a significant contribution independent of speed of information processing.

Recently, Salthouse (1991, 1993, 1994) distinguished between tasks of sensory-motor speed and more complex cognitive-speed tasks that require processes such as multiple comparisons and memory search. Although sensory-motor speed was found to be related to age-related differences in cognitive abilities, the age-related variance in IQ was by a greater extent reduced by controlling for cognitive speed.

As Hartley (1992) contended, there are strong and weak theoretical stances with respect to the role of information-processing speed and age-related declines in cognitive abilities. Consistent with Jensen's (1987a) mental speed position, advocates of the strong stance view the slowing with age of information processing as the result of changes in the underlying neural substrate. Reports of age-related reductions in neurotransmitters such as acetylcholine (Rogers & Bloom, 1985) and their possible links to memory problems in the elderly (Drachman, Noffsinger, Sahakian, Kurdziel, & Flemming, 1980) provide some converging evidence for this position. On the other hand, the fact that Strayer's study of cortical event-related potentials and comparison time (Strayer et al., 1987) failed to find a relation between comparison time and P300 might caution us about accepting the stronger theoretical stance. Proponents of the weak theoretical stance, in contrast, do not specify any causal mechanism; they treat the observed relations among the variables as grist for a theory. Performance on RT tasks may mirror differences in the neural substrate, but may just as well reflect motivational, strategic, and other higher order cognitive processes.

The data reported in this article permit further exploration of the relations among age, speed of information processing, free recall, and fluid intelligence, and afford tests of Salthouse's position that the decline in fluid intelligence with age is a consequence of the slowing of mental processes.

METHOD

Participants

A pharmaceutical firm solicited volunteers by distributing leaflets at public meetings and through announcements in newspapers. All data reported here were collected from participants assigned to a placebo condition. All volunteers were given a thorough physical examination to screen out those whose general health status was less than exemplary. Those with a history of, or any indications of, psychiatric disorders, neurological disorders, learning disabilities, or sleep disorders were excluded from participation as was anyone with a history of drug or alcohol abuse, or those taking any central nervous system (CNS) medication, including antihistamines with a CNS depressant effect. All volunteers suffering from lipidemia, chronic kidney or liver diseases, fibromyalgia, chronic fatigue syndrome, or endocrine disorders were also excused. Finally, only those volunteers with 20/20 corrected vision were accepted for participation. The 63 control participants (35 men and 28 women) who passed this stringent screening were all deemed to be in good health and remained so for the duration of the study. All participants were either living alone or with a spouse; no participants were institutionalized. The participants ranged in age from 26 to 80 years old (M = 46, SD = 12). Four participants were between 21 and 30 years of age, 17 were between 31 and 40 years of age, 16 were between 41 and 50 years of age, 13 were between 51 and 60 years of age, 10 were between 61 and 70 years of age, and 3 were between 71 and 80 years of age.

Apparatus

An IBM-486 compatible computer controlled the stimulus display in the free-recall, Sternberg, Posner, and Hick tasks and also served to calculate and record latencies for each trial on the Sternberg, Posner, and Hick tasks. The stimuli were presented on a Hyundai 35-cm high-resolution (VGA) color monitor. The participants' vocal responses on the Hick task were collected by an interfaced custom-made voice key. In the other RT tasks, participants responded by pressing on the keyboard. Machine language subroutines with millisecond accuracy calculated each RT (Graves & Bradley, 1987).

Materials

The following five tests were administered to each participant on each of three occasions separated by approximately 45 days.

Measure of Psychometric Intelligence. The Raven Advanced Progressive Matrices (RAPM) test (Raven, 1938) was used to estimate participants' fluid intelligence. Both the 12 practice and the 36 test items of the RAPM were administered on all three occasions. The standard instructions were read aloud by the examiner, and standard timing for both the practice (5 min) and test (40 min) items was followed.

Free-Recall Tasks. Two long-term free-recall tasks were used: organized and unorganized. In both, a list of 20 words composed of five words from each of four categories was displayed sequentially on a computer screen. In the organized task, although the presentation order of the words within each category was random, the words were blocked by category. As well, the order of the categories was itself randomized for each participant. In the unorganized task, the order of presentation of the 20 words was random, save that not more than two words from a single category might appear in succession. In both tasks, each word appeared on the computer screen for a duration of 2 s with an interstimulus interval of 250 ms. After the final word in each list, for a period of 30 s, participants were required to solve simple addition problems that appeared on the screen (e.g., $3 + 6 = ?$), providing their answers aloud. Immediately following these addition problems, participants were given 1 min to recall as many of the words as they could.

Words used in both the organized and the unorganized lists were drawn from Battig and Montague's (1969) category norms. All words were either five or six characters in length and both lists had a mean frequency rating of 45.

Sternberg Task. Participants were tested on a version of the Sternberg (1966) STM search test with a varied set procedure. On each trial, participants were presented with a sequential list of digits of varying length (1, 3, 5, and 7) to be held in memory (memory set). Each digit remained on the screen for 1 s. One second after the last digit in the memory set was presented, a warning beep was sounded followed 500 ms later by a single probe digit. The participant's task was to indicate, as quickly as possible, whether or not the probe had been a member of the previous memory set. Participants indicated its presence by pressing the *M* key on a standard keyboard; they indicated its absence by pressing the *Z* key. On each of the three test occasions, participants were given 64 randomly ordered trials, 16 of each memory set size, half positive (probe digit present) and half negative. Prior to each testing session, participants were given eight practice trials: one positive and one negative for each memory-set size, in random order.

Posner Task. A variant of Posner's (Posner, 1969; Posner et al., 1969) same–different task was administered on all three occasions. Participants were presented with pairs of uppercase, lowercase, and mixed-case letters (drawn from the set *A, a, B, b*) side by side, 0.5 cm apart on the screen, and were asked to determine, as quickly as possible, whether the letters were the same or different according to a particular rule. Participants indicated that the letters were the same by pressing the *M* key on a standard keyboard and different by pressing the *Z* key. In the PI condition, participants were asked if the letters were physically the same (e.g., *AA* or *bb*) or different (e.g., *AB* or *aA*). In the NI condition, they were asked if the letters had the same name (e.g., *Aa* or *BB*) or had different names (e.g., *aB* or *BA*). There were two blocks of 48 trials for each condition, with an equal number of same and different trials randomized throughout each block. The blocks were presented in an *ABBA* order. Whether the PI or NI condition was presented first was randomly determined for each participant on each occasion.

Hick Task. On all occasions, each participant was tested on a variant of the simple and choice RT tasks developed by Hick (1952) and more recently modified and employed by Jensen (1987a). Participants were seated approximately 36 cm from a computer monitor.

In the three test conditions, stimulus uncertainty ($\log_2$ of the number of equally probable stimulus alternatives) was set at one, two, and three bits. In the zero-bit condition, each trial commenced with the outline of an empty white-on-black square (1 cm^2) appearing in the center of the screen. Then, following a variable foreperiod, the square was filled with one of four colors (red, green, blue, or white). Participants were instructed to name the color as quickly as possible. There were four blocks of 12 trials and participants were informed prior to each block as to which one color was to be used in the succeeding bock. The order of the colors was randomized over blocks on each occasion for each participant.

Each trial in the one-bit condition began with the outline of two 1-cm^2 squares 10 cm apart on the screen, followed 1 s later by a warning beep, the variable foreperiod, and the filling of one of the squares with one of two colors. Participants were informed as to which two colors were to be used in each block of 12 trials. Blocks 1 and 2 used one pair of colors; Blocks 3 and 4 used the remaining pair. Though the two active colors within each block appeared with equal frequency, the order of presentation was random.

In the two-bit condition, participants were faced with a four-choice task. The trials in this condition began with the appearance on the screen of four equally spaced squares, 6 cm apart. All four colors were used in all four blocks of 12 trials. Subsequent to the warning beep and the variable foreperiod, one of the four squares was filled with one of the four colors. Participants were instructed to name the color as quickly as possible. Each block contained an equal number of presentations of each color, with the order of presentation randomized.

On all three occasions, all participants were tested first in the zero-bit, then in the one-bit, and finally in the two-bit condition. Within each condition, each color was associated with only one screen position; thus, screen position and color were redundant. The variable foreperiod in all conditions randomly ranged between 1 and 3 s. Prior to testing proper, participants were given four training trials on each condition. All latencies shorter than 100 ms or longer than 3 s were scored by the computer as errors.

Procedure

After a brief interview with a physician, each testing session began with the administration of the RAPM test. Participants then completed the recall, Sternberg, Posner, and Hick tasks in random order. There was a 10-min rest period between tasks. Each session lasted approximately 2½ hr.

RESULTS AND DISCUSSION

RAPM

As a group, the participants were of above average intelligence. The mean RAPM scores and the standard deviations for the three occasions are presented in Table 1. A rough estimate places an RAPM score of 18 near the 90th percentile for adults between 30 and 40 years of age (Raven, Court, & Raven, 1988). The practice effect suggested by the occasion means was confirmed in a statistically significant increasing linear trend, $F(1, 61) = 67.34$, $MSE = 6.07$, $p < .001$. Although performance generally improved with practice, the relative standing of the participants remained highly stable over time. The correlations between the scores on the three occasions were .83 (Occasion 1 and 2), .87 (Occasions 1 and 3), and .88 (Occasions 2 and 3). Consistent with previous studies of fluid intelligence, RAPM and age were found to be negatively correlated on all three occasions (Table 1). Of note is the fact that all participants in this study were given a thorough medical examination and were deemed to be in good health. Thus, the possible role of the terminal drop (Rabbitt, 1990) on age-related differences in fluid intelligence has been minimized. No difference was found between the mean scores of men and women, $F < 1$.

TABLE 1
RAPM and Free Recall: Descriptive Statistics

Variable	*M*	*SD*	Correlation With Age	Correlation With RAPM
RAPM 1	18.6	6.3	−.28*	
RAPM 2	20.7	6.5	−.17	
RAPM 3	22.2	6.9	−.28*	
Organized 1	8.5	3.7	−.20	.47**
Organized 2	11.3	3.9	−.32*	.50**
Organized 3	12.0	4.2	−.34*	.41**
Unorganized 1	7.5	2.9	−.12	.46**
Unorganized 2	9.4	3.3	−.07	.37*
Unorganized 3	9.8	3.4	−.16	.48**
Recall 1	16.0	5.7	−.18	.51**
Recall 2	20.7	6.5	−.21	.49**
Recall 3	21.8	7.0	−.28	.47**

Note. RAPM = mean score on the Raven Advanced Progressive Matrices. Organized and Unorganized = the number of items recalled on the organized and organized lists; Recall = combined organized and unorganized score on a given occasion. Digits 1, 2, and 3 identify the occasion.
$^*p < .05$. $^{**}p < .001$.

Recall

As exhibited by the standard deviations reported in Table 1, there was extensive variability in the number of items recalled by the participants on the two 20-item recall tasks. Scores on the organized task ranged from 2 to 20; scores on the unorganized task ranged from 2 to 19. Only two participants had reached the maximum attainable performance by the third session. As suggested by the means found in Table 1, tests for linear trends confirmed significant practice effects for both the organized task, $F(1, 61) = 65.86$, $MSE = 5.94$, $p < .001$, and the unorganized task, $F(1, 61) = 47.40$, $MSE = 3.46$, $p < .001$. Furthermore, all correlations between age and the linear and quadratic components of the participants' practice effects across the three occasions for both the organized and unorganized tasks were nonsignificant, suggesting no reason to presume that practice systematically varies with age.

The correlations between the recall scores, both within and across occasions, were all positive and substantial. There were moderate correlations between the organized and unorganized tasks on all three occasions, all statistically significant (.66, .65, and .71), and the average within-task between-occasion correlations (organized = .70, unorganized = .63, both statistically significant) indicated that performance was relatively stable over time.

As reported in Table 1, recall scores were found to be related to both age and intelligence. As in previous studies, age was negatively correlated with both recall tasks on all three occasions. The coefficients ranged from −.07 to −.34 and averaged −.20, indicating a weak but consistent relation between age and performance on the recall tasks. With respect to intelligence, both recall tasks were found to be correlated positively with RAPM on all occasions. The coefficients ranged from .37 to .50 and averaged .45 (all statistically significant). Given the internal consistency, a single recall score was derived from each participant on each occasion by summing their performance on the organized and unorganized tasks. The correlations that recall had with age and RAPM are also reported in Table 1. In sum, performance on the recall tasks appeared to reflect an enduring factor that is weakly associated with age and moderately predictive of fluid intelligence.

Speed of Information Processing

Sternberg Task. Accuracy on the Sternberg task for memory-set Sizes 1, 3, and 5 were above 90% on all three occasions for both negative-probe and positive-probe conditions. Participants had greater difficulty, however, with memory-set Size 7. Accuracy for Size 7 was below 90% on all occasions for the positive-probe condition and on the first occasion for the negative-probe condition. The stability of accuracy scores both within and across occasions was weak. The average between-condition within-occasion correlations were .20, .15, and .04, respectively. Additionally, there was little stability in accuracy over occasions; the between-occasion correlations averaged .10 (Size 1), .09 (Size 3), .13 (Size 5), and .27 (Size 7), with only Size 7 statistically significant.

The mean latencies for the memory-set sizes followed the typical pattern of results for this task (Stenberg, 1966). On all three occasions, the mean latencies increased linearly across memory-set sizes. This was true for both positive and negative probes. As shown in Table 2, latency was affected by practice; overall mean latencies, for both negative-probe and positive-probe trials declined across occasions.

All mean latencies, both within and between occasions, were positively correlated. The average pair-wise correlations between the latencies to negative probes for the four set sizes disclosed a considerable internal consistency in the performance of the participants: .75 (Occasion 1), .74 (Occasion 2), and .71 (Occasion 3). The same was true for latencies to positive probes: .72 (Occasion 1), .71 (Occasion 2), and .74 (Occasion 3). Consistent with Roznowski and Smith's (1993) findings, the average between-occasions correlations for both the negative-probe trials (Size 1 = .71, Size 3 = .76, Size 5 = .72, and Size 7 = .66) and positive-probe trials (Size 1 = .64, Size 3 = .75, Size 5 = .76, and Size 7 = .58) indicated moderate to strong temporal stability.

Table 2 illustrates the association between the overall condition latencies and both age and RAPM. There was a weak but consistent positive correlation between age and latency: The older the participant was, the slower he or she tended to respond. A consistent association also was found between latencies and

TABLE 2
Sternberg Task: Descriptive Statistics

Variable	*M*	*SD*	Correlation With Age	Correlation With RAPM
$^{-}$Probe 1	964	229	.18	−.42**
$^{-}$Probe 2	868	208	.36*	−.44**
$^{-}$Probe 3	838	199	.23	−.25*
$^{+}$Probe 1	890	197	.17	−.40*
$^{+}$Probe 2	800	182	.36*	−.38*
$^{+}$Probe 3	772	171	.25*	−.24
$^{-}$Slope 1	18.4	39.7	.01	.16
$^{-}$Slope 2	39.1	38.9	−.04	−.03
$^{-}$Slope 3	43.2	32.5	.06	.12
$^{+}$Slope 1	55.6	37.5	.11	−.18
$^{+}$Slope 2	60.9	35.2	.13	−.09
$^{+}$Slope 3	54.6	32.0	.03	−.03

Note. $^{-}$Probe and $^{+}$Probe = overall mean latencies across all memory-set sizes for the negative-probe and positive-probe conditions, respectively; $^{-}$Slope and $^{+}$Slope = the slope across memory-set Sizes 1, 3, and 5 for the negative-probe and the positive-probe conditions, respectively. Means and standard deviations are given in milliseconds.
$^{*}p < .05$. $^{**}p < .001$.

RAPM: Participants who scored high on the RAPM tended to have faster responses.

The slopes across the memory-set sizes generally corresponded to those reported in other studies (Table 2). Because of the lower accuracy rates for trials with memory-set Size 7, slopes were calculated using only memory-set Sizes 1, 3, and 5. The internal consistency of the slopes was weak; the mean correlation between the slopes for the negative-probe and positive-probe trials was .28. Furthermore, the slopes were relatively unstable across the three occasions. Similar to the findings of Roznowski and Smith (1993), the between-occasion mean correlations for the negative-probe and the positive-probe slopes were .28 and .21, respectively. Thus, not unexpectedly, the slopes showed no reliable association with either age or RAPM (Table 2).

Posner Task. In keeping with standard practice, analysis of the Posner task was restricted to those trials in which "same" was the correct response. Mean accuracy on these trials was 95% or greater on all three occasions for both the NI and the PI conditions. Because the performance of many participants was nearly error free, it is not surprising that there was little between-participant consistency in error rate within or across occasions. The correlations between the NI and PI accuracy scores within the three occasions were .09, .17, and .07. The correlations between occasions averaged .27 (NI) and .20 (PI).

Table 3 summarizes the descriptive statistics for the participants' latencies on

TABLE 3
Posner Task: Descriptive Statistics

Variable	*M*	*SD*	Correlation With Age	Correlation With RAPM
Occasion 1				
PI	624	108	.42**	−.45**
NI	689	119	.39*	−.33*
NI–PI	65	73	.01	.13
Occasion 2				
PI	571	107	.45**	−.35*
NI	652	114	.42**	−.36*
NI–PI	81	57	.00	−.06
Occasion 3				
PI	567	107	.52**	−.39*
NI	650	117	.35*	−.41**
NI–PI	83	66	−.22	−.10

Note. PI = physical identify; NI = name identity. The means and standard deviations are given in milliseconds.
$^*p < .05$. $^{**}p < .001$.

the Posner task on the three occasions. In keeping with the typical findings, the mean latencies in the NI condition were greater than mean latencies in the PI condition. As was the case with performance on the Sternberg task, there was an invariant pattern of positive relations among the latencies both within and across occasions. The statistically significant correlations between NI and PI latencies within each occasion reflected considerable internal consistency: .79 (Occasion 1), .87 (Occasion 2), and .83 (Occasion 3). Furthermore, the average between-occasions correlation for both the PI trials (.78) and the NI trials (.76) revealed a strong temporal stability.

Table 3 also illustrates the stable association that latency had with age and RAPM. In both the PI and the NI conditions on all three occasions, participants who responded more slowly tended to be older than those who responded more quickly. Latencies in both the NI and the PI conditions were all significantly negatively correlated with RAPM scores: Participants who scored high on the RAPM tended to have faster responses.

Mean NI–PI—the difference between a participant's mean PI latency and his or her mean NI latency—roughly corresponded to those reported in other studies (Posner, 1969). NI–PI was found to have moderate temporal stability; the average between-occasion correlation was .45. NI–PI, however, was not found to be associated with either age or RAPM (Table 3).

Hick Task. Regardless of stimulus uncertainty, whether zero, one, or two bits, participants made few errors on the Hick task. Mean accuracy rates for the three uncertainty conditions on all three occasions were 98% or greater. Despite the restricted variability, accuracy in one condition predicted accuracy in the others. Average between-condition correlations were .52 (Occasion 1), .73 (Occasion 2), and .74 (Occasion 3), all statistically significant. The between-participant stability in the accuracy scores over time was far more modest, however; the average between-occasions correlations were .15 (Condition 1), .37 (Condition 2), and .24 (Condition 3), with only Condition 2 statistically significant.

Within-condition latencies (RT) were found to have reliabilities comparable to those reported in previous studies (Jensen, 1987a). The Spearman–Brown corrected odd–even reliabilities ranged from .89 to .95. Furthermore, within each occasion, RT was highly consistent across uncertainty conditions; participants who were fast in one of the bit conditions tended to be fast in the others. The average between-condition correlations were .72 (Occasion 1), .83 (Occasion 2), and .81 (Occasion 3), all statistically significant. Participant's reaction latencies averaged over conditions (overall RT) were moderately stable across occasions. The average between-occasion correlation was .62. Table 4 illustrates the positive association found for overall RT with age and its negative relation with RAPM. The correlations between overall RT and RAPM observed here are within the range of correlations reported in other studies (for a review, see Jensen, 1987a).

Mean latencies for the three uncertainty conditions on all three occasions conformed to Hick's Law; latencies lengthened with increased stimulus uncertainty. The slopes for individual participants showed little temporal stability, however; the mean between-occasion correlation was .11. And as can be seen from Table 4, age was not a statistically significant predictor of slope. As was the case in the

TABLE 4
Hick Task: Descriptive Statistics

Variable	*M*	*SD*	Correlation With Age	Correlation With RAPM
Occasion 1				
RT	602	129	.31*	−.32*
Slope	61	72	−.12	−.07
Occasion 2				
RT	599	163	.16	−.22
Slope	69	58	−.19	.04
Occasion 3				
RT	550	111	.17	−.25*
Slope	72	38	.05	−.18

Note. RT = overall mean RT averaged across all three bit conditions; Slope = the slope of the regression across the three bit conditions. Means and standard deviations are given in milliseconds.
$^*p < .05$.

study by Barrett et al. (1986), these data also revealed no substantial association between slope and IQ.

Practice. The mean latencies for the three speed of information-processing tasks reported in Tables 2, 3, and 4 suggest that, on average, participants responded faster over occasions. The practice effects in all cases proved to be statistically significant. The improvements over time were then further examined for possible differences associated with age and RAPM score. All correlations between age and the linear and quadratic components of the participants' practice effects across the three occasions for all three speed of information-processing tasks were nonsignificant. The same was true when RAPM was correlated with the participants' linear and quadratic components. Thus, as others reported (Salthouse & Somberg, 1982), the performance of older adults on speeded tasks improves significantly with practice, but at a rate likely no different from that found for younger adults.

A General Latency Factor. Latencies for all three of the speed of information-processing tasks were reliable and consistently associated with age and RAPM; accuracy and slope were not found to be so. The situation with respect to slope is somewhat disturbing from the perspective of the mental-speed hypothesis, given that slope is deemed to be the purest measure of central processing time. Even when the slopes derived from the three speed of information-processing tasks used in this study were combined as predictors of RAPM, the multiple correlation was unpromising (.11). Although a detailed treatment of the issue cannot be presented in this article, the lack of stability found for the slopes is in fact what would be expected given the substantial between-condition correlations in all three tasks. When the between-condition correlations are as great as the test–retest reliabilities of the individual conditions—as was the case in all three tasks investigated here—the test–retest reliability of a slope approaches zero (Crocker & Algina, 1986). Furthermore, given the relative instability of the slopes, it is hardly surprising that the correlations with both age and RAPM were weak. Thus, slope data from these information-processing paradigms may be poor measures of individual differences and, more important, unsuitable for the testing of the mental-speed hypothesis.

Despite the problems associated with the slopes, there is nonetheless evidence for a general latency factor. Correlations between the latencies on the three speed of information-processing tasks reported in Tables 2, 3, and 4 were all positive and substantial on all three occasions. These latencies were subsequently averaged across conditions within tasks and over occasions to derive a single latency score per task (Sternberg, Posner, and Hick) per participant. All pair-wise correlations between these overall task latencies were substantial and statistically significant: Sternberg/Posner (.70), Sternberg/Hick (.58), and Posner/Hick (.61). The three task latencies were then submitted to a principal component analysis that confirmed the presence of but a single component with an eigenvalue greater than one, this component accounted for 75% of the variance. By summing scores for the three tasks, weighted by their respective loadings on the first component, a single latency score was derived for each participant. Although the Sternberg, Posner, and Hick tasks may share many cognitive components, for the purpose of further analyses, it was assumed that mental speed was the primary common constituent in the derived latency score. A single recall score was also secured for each participant by summing the organized and unorganized recall scores within each occasion and averaging across occasions. Finally, a single RAPM estimate was obtained by averaging each participants's three Raven scores. The correlations between these derived variables as well as age are presented in Table 5. As illustrated in the table, all pair-wise correlations were significant.

The next step was to test Salthouse's (1985) hypotheses regarding the relations between age, mental speed, and IQ. The significant correlations between latency and RAPM (−.51) and between latency and age (.40) provide further evidence of a link between a general speed factor, age, and IQ. As predicted by Salthouse (1985), the partialling out of age resulted in only a slight attenuation of the correlation between latency and RAPM to −.45, still statistically significant. Thus, the relation between mental speed and IQ appears to be largely independent of age. Additionally, Salthouse (1985) predicted that the correlation between age and IQ should virtually disappear if mental speed was partialled out. As reported in Table 5, the correlation between age and RAPM was −.28. After partialling out latency, the correlation between age and RAPM was reduced to a not statistically significant −.10. Again, this generally supports Salthouse's contention that a decrease in mental speed is responsible for all age-related declines in fluid intelligence.

To examine further the relations among the four variables, a path analysis was conducted. The predictor variables (age, latency, and recall) were arranged in a hierarchy consistent with the mental-speed hypothesis. Because age cannot be affected by the other two variables, it was given the initial position in the path.

TABLE 5
Correlations Between the Latencies on the Three Speed of Information-Processing Tasks and Age

Variable	Age	Latency	Recall	RAPM
Age	1.00			
Latency	.40*	1.00		
Recall	−.26*	−.34*	1.00	
RAPM	−.28*	−.51**	.56**	1.00

*$p < .05$. **$p < .001$.

Furthermore, it was presumed that latency could affect recall abilities, but that recall abilities could not influence latency. The fact that none of the four condition indices exceeded 20 indicates that the stability of the path coefficients was not seriously compromised by collinearity of the predictor variables. (For a discussion of condition indices and collinearity, see Belsley, Kuh, & Welsch, 1980.) The resulting path coefficients are presented in Figure 1.

The substantial fit of the model depicted in the path diagram is supported by a nonsignificant, $X^2(2, N = XX) = 1.35, p = .51$, and a goodness-of-fit index of model determination of .99. Although bearing in mind the particular variables examined in this study along with their ranges and variances, it is possible to draw several tentative conclusions from the pattern of path coefficients. Consistent with the partial correlations previously reported, the effects of age on fluid intelligence (RAPM) are essentially indirect through its influence on latency and doubly indirect through latency's effect on recall. Further supporting the mental-speed hypothesis is the fact that age appears to have little if any direct influence on recall. As with fluid intelligence, the effect of age on recall appears to be mediated by latency. Furthermore, latency has both a substantial direct impact on fluid intelligence and an indirect effect through its influence on recall. In summary, as suggested by Salthouse (1985), age-related differences in both recall and RAPM can be accounted for by differences in latency.

Although latency has a significant influence on recall, recall appears to have a substantial independent direct effect on fluid intelligence (RAPM). This would suggest that factors other than mental speed are required to fully explain individual differences in fluid intelligence. That is, even though decreases in mental speed may be responsible for age-related declines in fluid intelligence, differences in mental speed may not completely account for age-independent individual differences in fluid intelligence.

To reduce error variance, the path analysis was also run using the zero-order

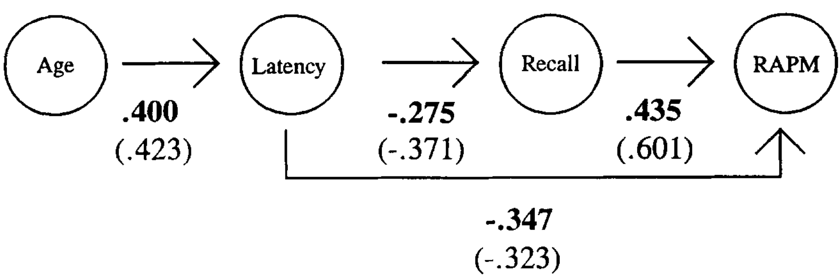

Figure 1. Path diagram and path coefficients for age, latency, recall, and RAPM. The assumed unidirectional causal hierarchy reads from left to right. Only statistically significant paths are depicted. Coefficients in parentheses are the result of a second analysis using the zero-order correlations corrected for attenuation.

correlation coefficients among age, latency, recall, and RAPM corrected for attenuation. The corrections were based on the test–retest reliabilities of latency, recall, and RAPM derived from these data. As can be seen in Figure 1 (coefficients in parentheses), the relative magnitudes of the path coefficients were virtually unchanged.

In light of these findings, the assumptions made concerning the nature of the latency variable are central to any conclusions or possible theoretical interpretations. Although the position that latency was given in the hierarchy is crucial for the empirical conclusion drawn from the path analysis, it is only a reflection of the more fundamental assumption concerning the nature of the derived latency variable itself. For the purpose of the earlier analysis, it was assumed that at least a large portion of the variance shared by the three speed of information-processing tasks was accounted for by mental speed and reflected little in terms of higher cognitive processes (e.g., control and organization). To test this assumption, latency can be correlated with the simplest possible speed of information-processing task: simple RT. Regardless of the simplicity or complexity of simple RT, it is safe to say that simple RT is less complexly determined than choice RT and latencies in the Sternberg and Posner tasks. Simple RT ought be less influenced by and contain fewer higher cognitive processes. This line of reasoning suggests that simple RT may be the best reflection of individual differences in mental speed. A strong association between the derived latency scores and simple RT could be seen as indicating a minimal role for higher processes in the latency scores, a conclusion consistent with the mental-speed theory. A weak association could be viewed as indicating a large role for higher processes or strategies, thus raising questions concerning the mental-speed explanation. For the purposes of this test, latency was recalculated after simple RT (zero-bit) was removed from each participant's overall RT score on the Hick task (latency). The subsequent correlation between simple RT and latency (.77) provides qualified support for the mental-speed position. Although approximately 60% of the variance in the latency scores can be accounted for by simple RT, it would appear that there remains plenty of shared variance among the speed of information-processing tasks that can be attributed to other shared components of a higher order.

To explore the nature of the general latency factor further, its contribution to variance in RAPM over and above that explained by simple RT was determined. Regressing RAPM separately on latency and simple RT yielded correlations of $-.51$ and $-.33$, respectively. The semipartial correlation between RAPM and latency absent simple RT was .40, $F(1, 60) = 12.08$, $p < .01$, indicating that components in latency other than those already present in simple RT account for approximately 16% of the variance in RAPM. After correcting the zero-order correlations for attenuation, the semipartial correlation between RAPM and latency rose to .88. The corrections were again based on the test–retest reliabilities derived from these data. Thus, components of the general latency factor in addition to mental speed appear to be critical for the correlation between RAPM and the latencies on the three speed of information-processing tasks.

Alternately, Salthouse's (1991, 1993, 1994) distinction between two types of mental speed—sensory-motor speed and cognitive speed—can be used to interpret the relations found among simple RT, latency, and RAPM. The fact that the correlation between latency and RAPM (−.51) was greater than the correlation between simple RT and RAPM (−.33) is consistent with the mental-speed position. So is the fact that components of latency, beyond those present in simple RT, account for substantial variance in RAPM scores. The question is one of interpretation concerning the nature of latency (cognitive speed). Is it the case that individual differences in cognitive speed reflect individual differences in the speed with which operations are executed (mental speed), or do they reflect differences in the control and organization of these cognitive operations? We believe this question is unanswerable at present.

In summary, latencies derived from the Sternberg, Posner, and Hick tasks can be viewed as reflecting in part a single, general latency factor. Furthermore, as suggested by Salthouse (1985), the age-related differences in fluid intelligence and recall can be accounted for by age-related declines in this factor. Additionally, the significant independent effect of recall on RAPM suggests that some portion of the age-independent individual differences in fluid intelligence is associated with factors other than differences in speed of response. Finally, in agreement with Salthouse (1991, 1993, 1994), our results indicate a need to differentiate those speed of information-processing tasks that are more sensory motor in nature from those that are more cognitive nature. We believe that a next important step would be to discover the basis of individual differences with respect to the general latency factor and to trace its role in recall performance and fluid intelligence.

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