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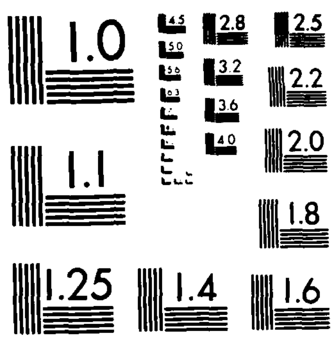

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University of Illinois at Urbana-Champaign

FINAL TECHNICAL REPORT EPL-83-4/NAMRL-83-1

Individual Differences and Age-Related Performance Assessment in Naval Aviators

Part 1: Battery Development and Assessment

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Prepared for

Human Performance Sciences Department
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We describe the construction of a test battery to measure the functional age profile of Naval aviators as this impacts on their flight proficiency. In the first phase of this study, reported here a battery of 21 task configurations is developed. These consist of a series of Sternberg memory search tasks measuring processing speed, a running memory task, tracking tasks performed alone and with the memory tasks, a dichotic listening task, and a computerized version of three tasks of spatial ability. The battery

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was administered to 15 subjects in each of the four age decades between 20 and 60. Factor analyses and ANOVAs performed on the data revealed three main clusters of effects: 1) age-related reductions in processing speed appeared to emerge beyond age 40. This slowing was general, not reflecting specific processes more than others. 2) Age-related changes in spatial and perceptual-motor ability appeared to emerge during the first decade. 3) The present data suggested little evidence for any age-related reduction in time-sharing or dual task skill that was not evident in the single task components. Part 2 of this report describes the validation of the battery accomplished by predicting performance on a Gat 2 simulated flight task from battery components.

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Final Report

Individual Differences and Age-Related Performance Assessment in Naval Aviators

Part 1: Battery Development

1. Introduction

1.1 Overview

This report focuses on the currently ongoing research and development effort between the Aviation Research and Engineering Psychology Laboratories of the University of Illinois and the Naval Aerospace Medical Research Laboratory, Pensacola, Florida. The objective of this work is the development and validation of an information processing performance battery that can be used for the initial selection of student aviators and also for the longitudinal assessment of experienced aircrews. This work is part of the U.S. Navy's effort to develop age-free biomedical standards which take into consideration the large individual differences found within and across different chronological age groups.

The use of chronological age limits for the selection and retirement of pilots is based on the assumption that chronologically younger individuals are more likely to perform successfully in the demanding environment of military aviation. Chronological age limits as a criterion for flight classification decisions reflects the fact that the effects of age on the performance in military aviation weapons systems are largely unknown. However, the use of chronological age as a criterion for flight classification has received critical scrutiny by the U.S. Navy in recent years leading to the demand for the development of age-free biomedical standards. The research reported here outlines a currently ongoing effort to develop an information processing performance battery using aviation relevant task structures that permits the assessment of an individual's performance within and across different age groups. If the performance battery obtains a high level of diagnosticity, it could be used for the augmentation of existing selection and classification procedures as well as for the longitudinal assessment of aviators. The individual's performance on the battery will be expressed in terms of a functional age profile (Borkan and Noris, 1980) which represents an elaboration of the functional age index (e.g., Gerathewohl, 1977). The functional age profile indicates an individual's performance relative to his chronological age peers on the age-affected information processing capabilities that are being assessed. Relatively better performance will be equated with younger functional age. The functional age profile should prove to be of greater diagnostic value than a single index in that it is more sensitive to the differential aging (i.e., non-unitary) process within the individual.

1.2 The Problem and Approach

If aging was a unitary process across individuals, then the development of such a performance profile would not be necessary. However, in a series of articles dealing with the results of the Normative Aging Study conducted by the Veterans Administration's outpatient facility in Boston, Massachusetts, it was stated that aging is not a unitary process and that at a given chronological age an individual may appear to be older or younger in the various aspects of aging (Bell, 1972). This heterogeneity of the aging process is reflected differentially in the performance of individuals in particular task domains.

It would go far beyond the scope of the current discussion to provide an in-depth review of the existing aging literature. Other sources may be consulted for this purpose (e.g., Welford, 1958; Gerathewohl, 1977; Birren and Schaie, 1979; Poon, 1980; Craik and Trehub, 1981; Hunt and Hertzog, 1981). Most of the investigations conducted within the aging framework have relied almost exclusively on the comparison of rather extreme age groups (e.g., 20 and 70-80 years) which not surprisingly suggests a rather dramatic decline in performance capabilities. Besides the rather serious methodological problems that can lead to a confounding of the obtained results with non-age-related factors (e.g, cohort effects), it is doubtful that aging can be represented by a monotonically decreasing linear function. The profile of age-related changes across the age range of 20 to 60 within the current research framework, may in fact look rather different.

A contrasting policy is based upon the concept of functional age (Gerathewohl, 1977). Certain individuals may "age" more rapidly in some or all components of performance than others. Hence, a given individual may be functionally old or young, independent of his or her chronological age. Furthermore, since not all components of performance age (either chronologically or functionally) in synchrony, it is more appropriate to speak of a functional age profile, than an index.

The strategy of research we report is schematically represented in Figure 1 which indicates three sources of variance in human abilities: (a) Those abilities that systematically decline with age, (b) those abilities that are relevant to information processing, and (c) those that are relevant to flight proficiency. Our research objective is to identify the common variance among all three domains--the area (1) in

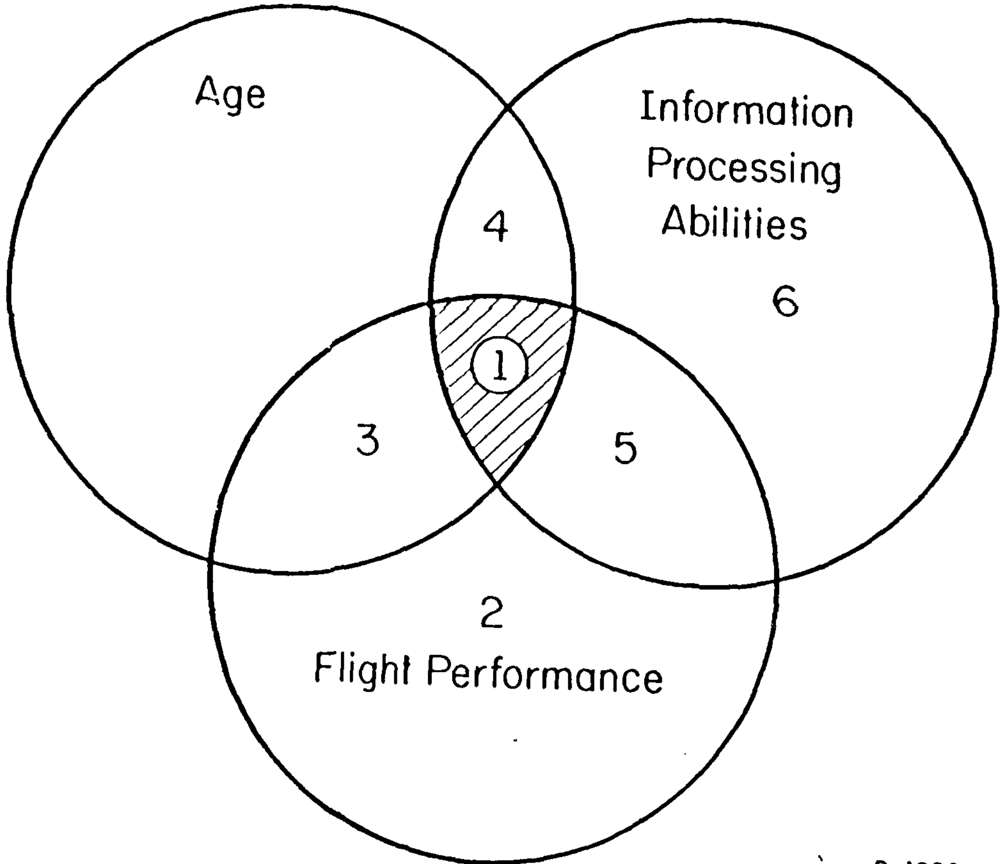

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Figure I1: Sources of performance variance investigated in the present research.

black. This approach limits the scope of our research somewhat. For example, there are clearly variables relevant to flight performance that are not directly related to information processing skills: (Area 2) - Many aspects of pilot judgment and motivation, for example, fall into this category (Jensen, 1981). Some of these abilities furthermore may also correlate with age (Area 3)--visual capabilities related to accommodation represent a typical example (Simonelli, 1983). Finally, there may well be age-related changes that are unimportant for flight (Area 4), and information processing skills related to aviation that are unaffected by age (Area 5).

Our research strategy will be to focus initially upon the domain of information processing skills and develop a battery, heavily guided by our own and other's (North and Gopher, 1976; Imhoff and Levine, 1981) analysis of the processing components involved in aviation (Areas 1 & 5, possibly including some of Areas 4 & 6). Then in the first phase of our study, which we report here, we shall discriminate between Areas 1 & 5 by administering the components of our battery to four groups of subjects spanning the four decades of the age range from 20 to 60. In the second phase of our study, to be described in the forthcoming report, we will attempt to focus the battery specifically onto Areas 1 & 5 and eliminate components related to 4 & 6. We do this by using our battery to predict flight performance in the aircraft simulator. We should note that both Areas 1 & 4 are of equal interest. That is, it is equally important to establish what flight-related components do <u>not</u> change with age, as to identify the ones that do.

1.3 Approaches to the Specification of the Abilities and Processes Relevant to Flying

Se.eral possible sequences are available from which the abilities and processes crucial to flying may be inferred. One possibility consists of analysis of unsuccessful pilot behavior. Another approach might consider an analysis of specific flying tasks to allow the inference of abilities and processes crucial to the performance of that maneuver. By correlating and interpreting the results of these approaches it is possible to develop a framework characterizing pilot performance in terms of underlying abilities and processes. The general model of human information processing can then be related to those abilities and processes to provide a conceptual framework within which a battery of tasks can be developed to serve as pilot-screening devices.

Analyzing the causes of successful and unsuccessful pilot behavior, Gerathewohl (1977) was able to identify a set of 14 major psychological factors which appeared to determine successful or unsuccessful pilot performance. Although the 14 psychological factors may be useful for certain applications, for the development of a test battery, however, at least two major limitations can be seen. First, the factors identified are much more general than the abilities and processes dealt with within the model of information processing. Secondly, many of the factors specified are personality and social factors, and are therefore outside the domain of the proposed research.

A different approach to determining the abilities and processes crucial to flying is to analyze specific flying tasks and construct a taxonomy of behavioral skills required to perform these tasks. Meyer, Levison, Weissman, and Eddows (1974) constructed such a taxonomy for tasks required in pilot training. They started with a model involving cues from external and system sources which, when detected and interpreted correctly led to mental actions. The mental actions led to motor actions upon the system, as well as further mental actions comparing the motor action and resulting cue changes to some performance standard. Task analyses were than performed in terms of these cues, mental actions, and motor actions. The analyses were very specific. Cues were specified in terms of visual, auditory, motion and control cues, complexity, type of information processing required (specific cue, memory recall, multicue, or iterative processing), and type of decision processing required (simple judgment based upon fact or complex based upon estimation). Motor actions were similarly classified according to their continuity, control output, and complexity.

Although such a taxonomy like that of Meyer et al. appears useful for identifying certain behavioral skills, for the purpose of building a screening battery the taxonomy is too specific--so that motor actions are specified in terms of specific output controls rather than underlying abilities--and is too vague so that specific information processing skills are difficult to determine.

With regard to the information processing skills involved in flying, none of the approaches are able to provide the detailed information that is necessary for the development of a screening battery based upon cognitive and information processing capabilities. The possible reason for this shortcoming is the overemphasis that was placed on observable behavior in pilot training research while neglecting the cognitive and information processing skills. We have therefore attempted to relate flight phases directly to information processing skills.

During almost all phases of flight the pilot must monitor information sources from a variety of modalities, including visual, auditory and kinesthetic cues. Relevant visual cues in particular arise from both the external environment and information sources within the cockpit. It is important for a successful pilot to perceive and interpret these sources quickly (perception, perceptual speed), and respond quickly (reaction time). Since these are multiple sources, the pilot must be able to focus on the critical cues (selective attention), switch attention as different cues become relevant at different times (switching attention), and often integrate cues from diverse sources inside and outside the aircraft's cockpit (divided attention). Moreover, since more than one task will be frequently relevant at the same time, the pilot must be able to divide attention between different inputs and activities (time-sharing).

Frequently, the pilot's task is more complex than merely perceiving the appropriate input quickly and making a relatively automatic response. In those cases where the response is not automatic, the pilot must search the input sources for additional information (visual scanning) and encode the inputs for further information processing. For example, the attitude indicator by itself may not provide sufficient information for a response. The pilot must search memory for the appropriate reading at that stage of flight (memory search), perhaps form an image of the reading (visualization), and compare the image or internal model to the actual reading. The pilot might also refer to knowledge of the mission and the aircraft, and integrate that information while mapping relationships from previous experiences onto the present situation (problem solving). The variety of alternatives highlight the important role of decision making in flight.

These examples can only touch the information processing skills that are required from the pilot in routine manual flight performance. The situation becomes much more complex when areas like air-to-air combat, carrier operations, or emergencies are considered. To the authors' knowledge too little is known about the relevant information processing skills required in those situations. However, it is assumed that the central processing speed must increase, the decision making will have to be guided by the willingness to accept certain risks, and the pilot must have an internal model of both the system dynamics (aircraft and weapons), and the state of other aircraft in the surrounding airspace. For the purpose of the initial development of a screening battery only information processing skills necessary in a normal instrument flight situation with communications will serve as guidelines. Table 1 shows a sample of these skills together with their relevant flight tasks.

Assuming that the listed information processing skills play a crucial role in flying, the next step is to review the research that has been done on those skills and to identify the tasks which reliably indicate individual differences in those skills.

1.4 Information Processing Skills of Concern

Using the general human information processing model discussed previously and the brief overview of some of the cognitive skills relevant to successfully operate an aircraft the next step will be to relate those skills to individual differences and age-related variance. It is important to mention at this point that individual differences and age-related variance are two concepts that are closely tied together. In reviewing the literature on age changes in intelligence as measured by psychometric tests, Hunt and Hertzog (1981) point out that individuals that differ slightly in intelligence at age 20 will differ much more by the age of 60. The same results were shown for a

Table 1

Information Processing Interpretation of Some Flight Tasks

Flight Task	Process
Preflight:	
a) collect weather and mission information	Visual and Auditory Perception
b) interpret weather and mission information within the framework of intended flight	Decision Making based on Probabilistic Data
c) based on interpretation decide on necessary actions to complete mission successfully	Problem Solving
d) preflight aircraft for malfunctions	Visual and Auditory Perception, Decision Making
Takeoff:	
a) observe changes in instrument readings and external sources	Visual Perception
b) rotate aircraft at predetermined airspeed and establish climb out	Decision Making based on absolute data, Visual Perception
c) anticipate location and direction of aircraft movement (flight path)	Imagery, Mental Rotation
Cruise:	
a) maintain constant monitoring of flight instruments and external sources	Visual and Auditory Perception
b) identify inputs quickly and accurately and act appropriately	Signal Detection (Perception), Decision Making
c) maintain information for immediate processing	Short Term Memory Capacity and Retrieval Speed

variety of social, psychological and physiological indicators (Maddox & Douglas, 1974). Those findings will have a direct impact on what tasks are to be selected and what experimental design will be used.

A preliminary review of several surveys dealing with age-related effects and individual differences was conducted (Gerathewohl, 1977; Hunt and Hertzog, 1981; Imhoff and Levine, 1981; Poon, 1980; Salthouse and Sonberg, 1982; Rose, 1974). This review allows us to make the following general assertions:

1) Perceptual and sensory capabilities decline with increasing age.
2) A decrease in the speed of mental functioning occurs with age.
3) Older persons appear to have a more conservative criterion on signal detection tasks and decision making.
4) The effect of age on attention is not quite clear although it is a well established fact that individual differences in selective attention capability are a strong performance predictor in "real world" situations.
5) Simple reaction time as well as choice reaction time slows down over the years. But again, large individual differences exist. A reasonable component of this shift is attributable to a more conservative response criterion, so that responses are slower but more accurate.
6) The speed of information retrieval from short term memory as well as from long term memory seems to be negatively affected by age.
7) Information retrieval from semantic memory does not seem to be affected by age. However, strong individual differences

seem to exist. Furthermore, retrieval speed from long term memory may be compensated by more fertile associations formed as a result of experience.

8) The speed of mental rotation of visual information appears to slow down.

9) Age-related losses in the accuracy of information retrieval from short term memory seem to exist. These drops are small, however, and may be traced back to the general slowing of the mental processes.

10) Concerning the area of problem solving it may be argued that it becomes more difficult with advanced age when a) rapid mental computations are required, b) the problem makes demands upon working memory in such a way that the memory task must be executed in a dual task situation, and c) the effects of prior learning are disregarded.

11) Older persons usually show greater field dependence in their perceptual style. Field-dependent subjects require more time to process visual information and are less effective in their visual search behavior.

Although this brief summary seems to suggest a rather negative picture of the aging process it has to be pointed out that these are strictly laboratory results based on randomly selected samples. Furthermore, the findings are generally based on contrasts between extreme groups (e.g., 20 year olds vs. an "old" group with a mean age of 70). This does not allow for the profile of age change <u>across</u> the ranges of ages of interest to be assessed. To the authors' knowledge no serious attempt has been made to investigate these findings on a homogeneous professional group (for example, pilots) and correlate these findings with the subjects' performance on their highly practiced professional skill. Finally, it should be emphasized that in all of the categories listed above the variance across individuals within an age group is large, normally exceeding the variance between groups. Hence, there are individuals at the older levels who perform consistently better than their chronologically younger counterparts.

Although there exists a large number of studies on aging in humans most of the research has not been conducted on samples of pilots. The extent to which a study can be generalized to the aging process in the pilot depends to a large degree on the similarity between the subject population, and in this case, naval aviators. Naval aviators represent a select population. They are better educated than the general population and are more physically fit.

The One-Thousand-Aviator-Study (MacIntyre et al., 1978), still being pursued at the Naval Aerospace Medical Research Center in Pensacola, Florida, is one of the very few lognitudinal studies conducted on pilots. But neither this study nor data collected at the Lovelace Foundation for Medical Education and Research (Proper, 1969) attempted to correlate mental functions with in-flight performance data. Szafran (1969) analyzed specific perceptual and psycho-physiological measures to determine if significant age differences were reflected in the pilots' performance. The interesting result was that for almost every measure, the pilots' age, ranging from late 20s to the early 60s was irrelevant to flight performance.

1.5 Rationale for Design of the Battery

In our initial selection of the tasks for the battery, we were guided jointly by our (and others) analysis of the flight task, as well as by component information processing tasks that others (e.g., Rose,

1974) have successfully validated as test battery items. These analyses and reviews lead us to incorporate the following elements..

Processing speed. Because much of the pilots' behavior in critical high load situations must be rapid and accurate, we have included reaction time measures as major components of the battery. These involve both auditory and visual inputs (as the pilot must respond to both kinds of stimuli), and manual responses. In addition, we have included the critical instability tracking task (Jex, McDonnel, & Phatak, 1966) as a specific measure of continuous processing speed in manual control.

Memory. Much of a pilot's activity requires memory operations. Hence, our reaction time tasks are based upon the Sternberg Memory Search Task (Sternberg, 1975). Because we wish to assess the speed of memory search the tasks are performed at two different memory loads. This allows us to estimate the "slope" of the function relating set size to RT and therefore the search speed. Cavenaugh's (1972) investigation indicates that differences in slope offer a reliable estimate of differences in memory capacity (Smith & Langolf, 1981). Finally, since we believe that age-related (or individual) differences in memory may be different for different kinds of material, we have included Sternberg tasks involving both spatial (random dot patterns) and verbal (letters) material.

Manual control. In addition to the critical tracking task we have included a second order tracking task. This incorporates dynamics more similar to those confronted by the pilot, requiring some degree of prediction to generate stable control.

Time-sharing and attention. This is perhaps the most critical element of pilot performance in high load conditions (North & Gopher, 1976). We have incorporated estimates of time-sharing ability in three different forms: (1) The Sternberg tasks are performed concurrently with second order tracking as well as by themselves. This allows us to examine time-sharing between activities that place demands on both similar and dissimilar processing resources within the human processing system. Similar resources are demanded when the Sternberg task, like the tracking task with which it is shared, uses both visual input and spatial material. Dissimilar resources are engaged when the Sternberg task uses auditory input and verbal material. Wickens (1984; Wickens & Benel, 1981), suggest that these circumstances may use substantially different time-sharing skills. (2) A running memory digit cancelling task is also performed alone and time-shared with tracking. (3) We have incorporated the dichotic listening task (Gopher, 1982), providing measures of both focussed attention and attention switching, that has been validated as a predictor of flight performance in the Israeli Air Force.

Spatial ability. It goes without saying that spatial abilities are critical in aviation. To tap these abilities we have incorporated three elements into the battery. As noted above, a spatial variant of the memory search task, along with the spatial second order tracking task have been incorporated. In addition, we have included computer generated versions of three elements taken from the ETS kit of spatial abilities tests: A figure rotation test, a maze tracing test, and an embedded figures test. The latter serves also as a measure of field-dependence, a cognitive ability sometimes associated with flight performance.

Together the tasks and configurations we have thus generated are represented in Table. 2. The table specifies each task in terms of the three dimensions of Wickens' (1980) multiple resource

Table 2

Summary Table of the Information Processing Tasks

Selected and Used in the Battery

Experimental Tasks

Modalities / Tasks		Set-Size	Single Tasks			Dual Tasks
			Stimulus	Central Processing	Response	
Tracking	One-dimensional 2nd order comp.		V	S	M	Tracking+ 7 conditions
	Critical		V	-	M	
Sternberg (Memory Search Task)	1	2 4	V	V	M	X X
	2	2 4	A	V	M	X X
	3	2 4	V	S	M	X X
	4	2	A	S	M	
Delayed Digit Recall (2 dig. back)			A	V	M	X
Spatial	Card Rotation		V	S	M	
	Hidden Patterns		V	S	M	
	Maze Tracing		V	S	M	
Dichotic Listening			A/A	V	M	

V=visual V=verbal M=manual
A=auditory S=spatial

model of human performance: stages of processing (P = perceptual/central, R = response); codes of central processing (S = spatial, V = verbal), and modalities of input (A = auditory, V = visual).

2. Method

2.1 Subjects

Sixty males between the ages of 20 and 60 served as subjects. For the purpose of statistical analysis the subjects were separated into four different age groups of 15 subjects each: Group 1 (G1) 20-26; Group 2 (G2) 27-39, Group 3 (G3) 40-52, and Group 4 (G4) 53-60. The subjects were all volunteers that had responded to ads in local newspapers. All reported to be in good health with 20/20 corrected vision and normal hearing. Each subject was paid $3.00 per hour.

2.2 Tasks

Visual-verbal Sternberg (VV). Prior to each trial the subject was presented a memory set of either 2 or 4 randomly chosen letters. Each letter was presented for 3 seconds for two cycles. Following this presentation, a series of probe letters were presented of which 50% were drawn from the memory set. The interval between each response and the next stimulus randomly varied between 1 and 4 seconds. On a two button control switch the subject indicated whether each stimulus was or was not a member of the memory set. Correct response times for yes's and no's were averaged and the proportion of correct responses recorded.

Auditory-verbal Sternberg (AV). This task was identical in format to the VV task except that the stimuli were presented auditorily over the headphones. Again, set sizes of either 2 or 4 were employed.

During initial presentation the memory set was cycled through twice.

Visual-spatial Sternberg (VS). This task was analogous to the VV task, except that the "alphabet" from which the stimuli were drawn was constructed by generating the 15 possible pairs of positions created from two lights positioned in a 2 rows x 3 columns matrix. The lights were presented in sequence with the first light remaining on for 300 msec, followed immediately by the second, which remained on for 300 msec. Because the lights in each pair could be presented in sequence, the 15 possible pairs generated 30 possible stimuli when both orders of a pair were considered. Set sizes of 2 or 4 were employed.

Auditory-spatial Sternberg (AS). The AS task was analogous to the VS except that the 2 x 3 matrix was constructed in auditory space. The three horizontal positions were created by tones played to the left ear, right ear, and midplane of the head (equal intensity to both ears). The two vertical positions were created by employing low or high pitched tones.

Delayed digit cancelling (DDC). In this task the subject heard a random sequence of digits. After each digit was heard the subject was required to indicate the value of the digit two back in the sequence by pressing the appropriate button on a keyboard. For example, in the sequence "1, 4, 7, 2," after hearing the digit "7" the subject would respond "1," and after "2" he would respond "4." The subjects had to respond within 3 seconds. Otherwise, a new stimulus was brought up automatically. A new digit was presented 1 second following each previous response.

Second-order tracking. The subject manipulated a spring loaded joystick in the left-right direction with the right hand in order to minimize the error on a horizontal compensatory display. Control was exercised using second order (double integral or acceleration) dynamics of the form $Y = K/S^2$. The subject attempted to track a band-limited disturbance input with an upper cutoff frequency of 0.32 Hz. When presented concurrently with the visual Sternberg tasks, the tracking error was displayed immediately above the Sternberg stimulus. In this case the Sternberg task was responded to with he left hand. For all dual task combinations subjects were told to give equal emphasis to both tasks, emphasizing both, speed and accuracy.

Critical instability tracking task. In this task, described by Jex, McDonnel, and Phatak (1966), the subjects moved a spring-loaded joystick in a left-right direction in order to stabilize an unstable positive feedback element with dynamics of the form: $Y = \lambda/S - \lambda$. The critical root λ, influencing the stability of the system increased at first at a fast rate (F) and then at a slow rate (F/4) until control was lost. The subjective impression of this task is that of balancing a dowell rod on the end of one's finger, while the rod progressively shortens in length. The performance measure is λ_c, the level of λ at which control is lost.

Maze tracing. Subjects viewed a computerized maze of the form shown in Figure M1. They were required to decide as rapidly as possible whether or not there was an open path from start to finish and indicate their response with a yes-no button press.

Embedded figures. Subjects viewed a target pattern of the form shown at the top of Figure M2, followed by a series of stimuli, one example of which is shown below. For each stimulus they were to decide as rapidly as possible whether or not the target pattern was contained in the stimulus, and indicate their response with a yes-no button press.

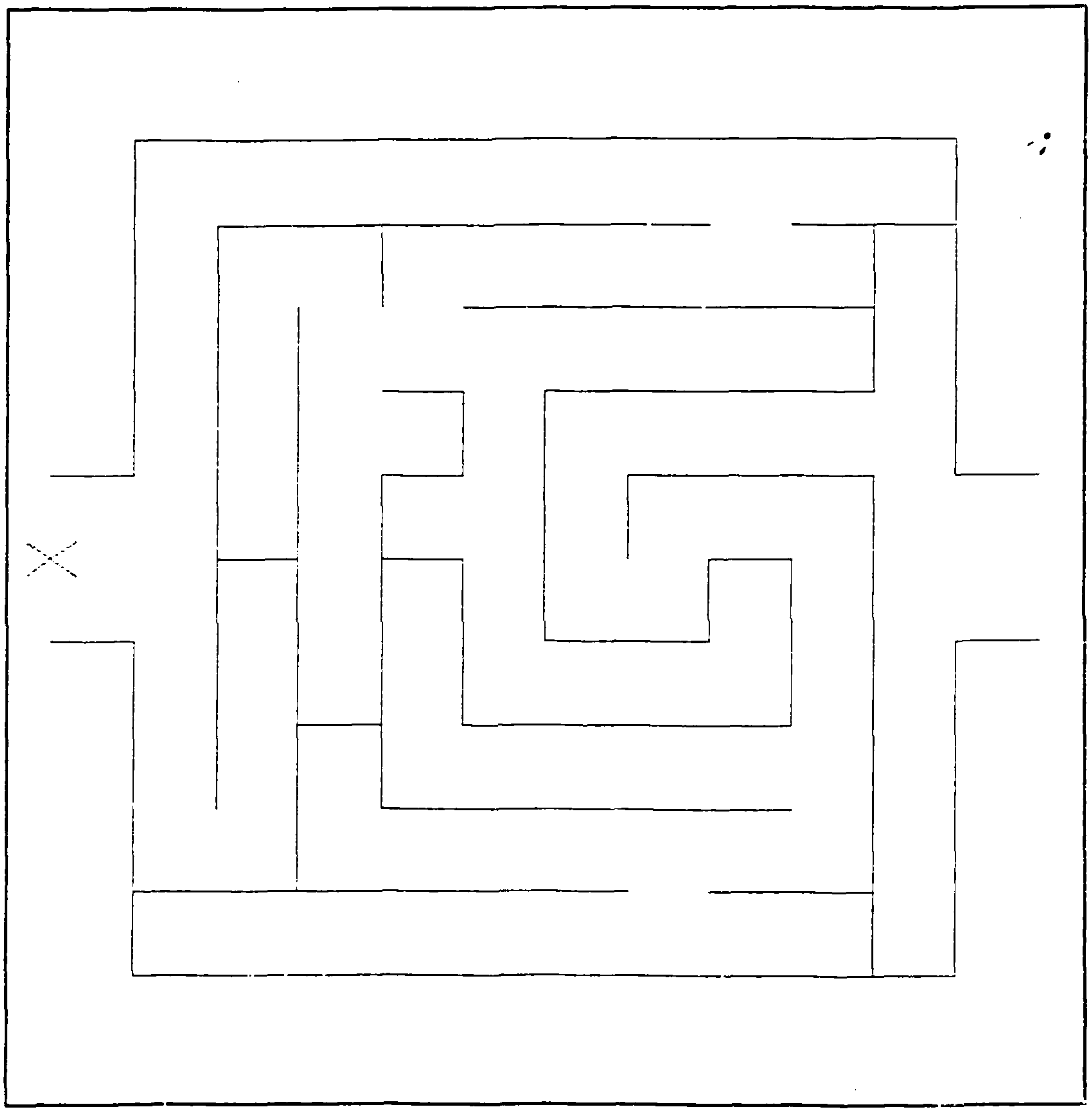


Figure M1: Maze tracing stimulus.

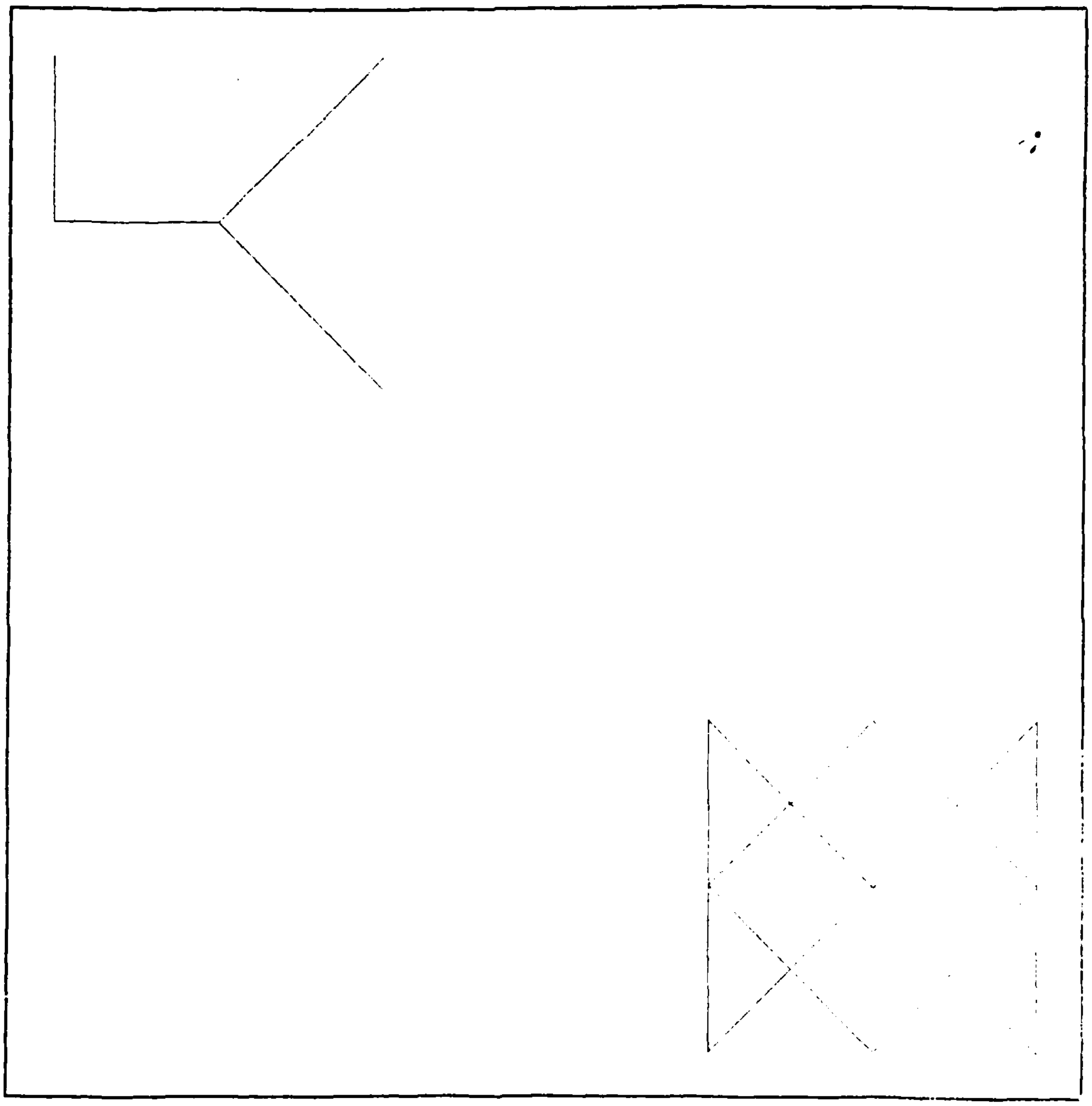


Figure M2: Embedded figures task.

Figure rotation. Subjects viewed a series of figure pairs of the sort shown in Figure M3. Each figure was to be judged according to whether one figure could be rotated to be congruent with the others. Again, the yes-no response was given with a button press.

Dichotic listening. This task, described in detail by Gopher (1982) presents subjects with a series of word and digit pairs, simultaneously presented to the two ears. During phase 1 (focussed attention) the subject is to report only the digits presented to one ear and ignore those to the other. During phase 2 (attention switching) a cue is presented on one ear to switch the relevant ear, and the subject is judged on the accuracy of reporting digit on the now-relevant channel. To the extent that switching is slow, the first digit after the cue will be missed, or the digit on the non-relevant channel will reported.

2.3 Apparatus

A PDP 11/40 minicomputer was used to generate the stimuli and record the subjects' performance. The computer was interfaced with a Hewlett-Packard display generator, a control stick, and two interchangeable keyboards. Auditory stimuli were generated by a Centigram Corporation Mike-2 unit, interfaced to the PDP 11/40. The subjects sat in a sound and light attenuated booth approximately 90 cm from a CRT. The CRT was used to present all the visual stimuli to the subject. The only task that was not computer-generated was an English version of the Dichotic Listening Task. This task had previously been recorded in a professional recording studio. It was copied onto a stereo-cassette and was played to the subjects via a stereo-cassette player. The subjects received the messages through a headset and recorded their responses on a recording sheet. Throughout the entire experiment subjects and experimenter communicated by intercom operating

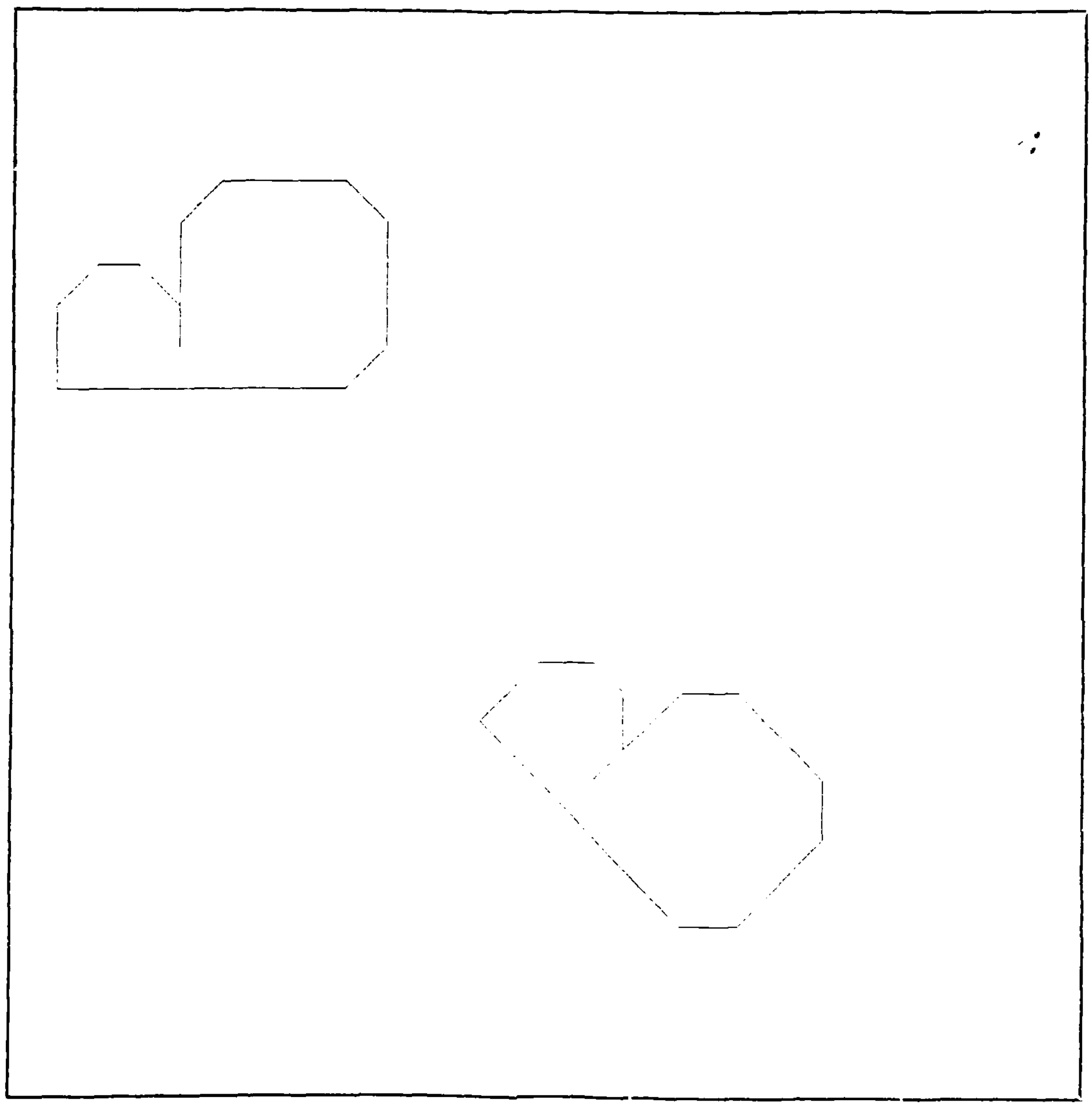


Figure M3: Figure rotation.

through headsets.

2.4 Procedure

All subjects received three replications of each of the 20 computer-based trials given in two sessions. The first session included a 1 minute familiarization run of each task and a 2 minute test trial. The second session, following the first after a 45 minute rest period, consisted of one 2 minute replication of each configuration. The Dichotic Listening Task which contains introduction, practice and 48 individual tests was broken up into two parts. During Session 1 each subject was given the introduction, practice, and 24 of the test trials. During Session 2 each subject was given the remaining 24 test trials. The total duration for Sessions 1 and 2 combined was 4 hours per subject.

Results

The present data may be examined from three distinct perspectives:

(A) What sort of performance did the tasks produce? In particular how did task manipulations affect performance?

(B) What kinds of individual differences in processing underlie the data? This is revealed by correlational and factor analysis.

(C) What were the effects of age, both on task performance scores, as in perspective A, and on factor scores as in B?

We shall summarize the results by describing A and B, and within each section, after addressing the main effects across all ages, consider the specific age related differences. Our discussion will then integrate these areas.

(A) MAIN PERFORMANCE EFFECTS (tracking and memory search). Because many of the tasks showed some practice effects and the data were a good deal more stable on Session 2 than 1, only the data of Session 2 will be reported below (see Appendix A for a listing of practice effects from S1 to S2).

Figure R1 presents the joint effects of memory set size, task type (auditory-verbal, AV; visual-verbal, VV; and visual-spatial, VS), and task load (single-dual) on latency of the memory search task. Considering both the single and dual task data together, it is evident that latency slows as memory set increases ($F = 208$, $p < .001$); latency is fastest with the V-V condition, intermediate with A-V, and slowest with the V-S ($F = 555$, $p < .001$). Furthermore, there is an interaction between stimulus type and set size such that the search rate is slower for the visual-spatial version than for the two verbal versions ($F = 73.7$, $p < .001$).

Response time is also slowed under dual task conditions ($F = 16.2$, $p < .001$), but this effect differs with stimulus type. When the stimuli are verbal (the two functions on the left), the decrement is smaller when the auditory as opposed to the visual modality is used, a predictable effect from multiple resource theory (Wickens, 1984). However, the effect of processing code (verbal-spatial) is less predictable. The visual spatial version, which shares most resources with tracking, appears to show almost no decrement at all. This latter counterintuitive finding becomes somewhat more interpretable when the interference of the memory search task on second order tracking error is examined.

The tracking error data are shown in Figure R2. Here we see that tracking error for all tasks is well above the single task baseline of

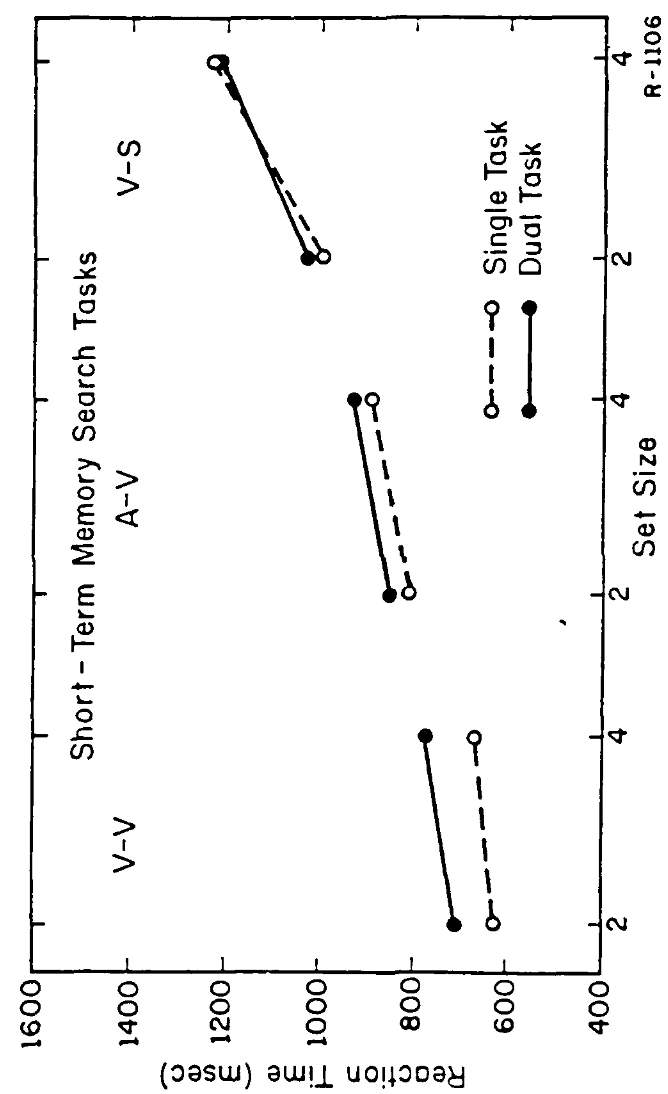


Figure R1: Sternberg memory search task performance collapsed across the four age groups, in single and dual task trials.

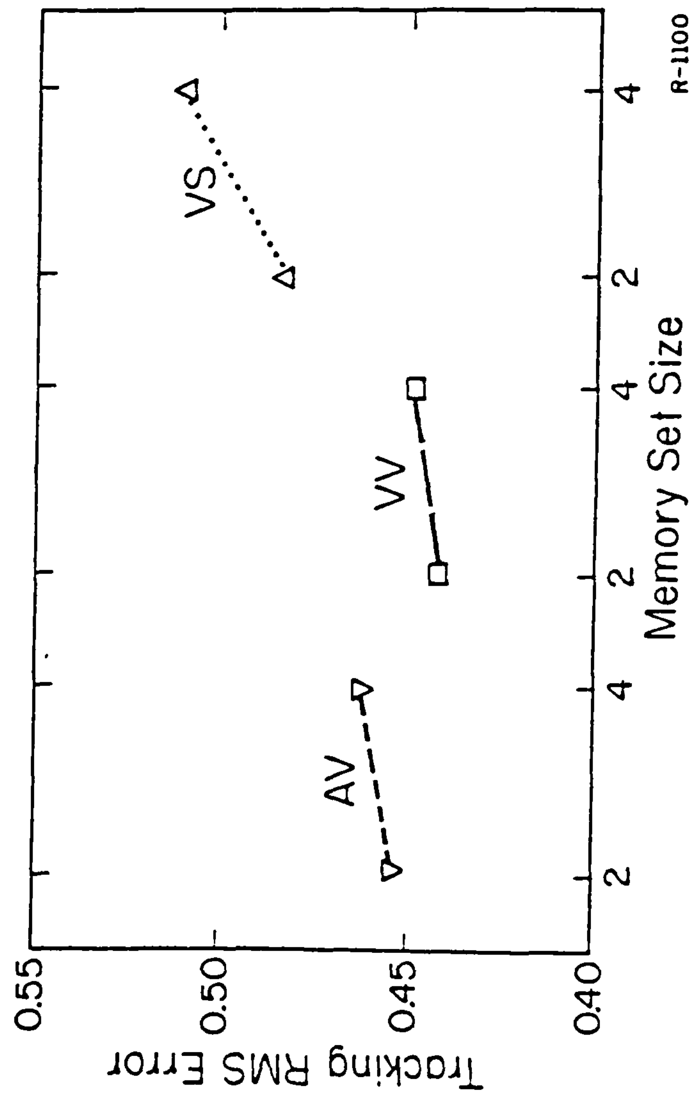


Figure R2: Effect of stimulus type and memory set on second order tracking error.

of interference from that which was obtained for reaction time. That is, tracking error is now highest in the presence of the V-S memory search task, and nearly equivalent for the two verbal tasks, but slightly lower when the stimuli were visual ($F = 46.9$, $p < .001$). In addition, stimulus type and set size interact, with the increased memory load producing a greater effect on tracking performance when the stimuli are spatial than when they are verbal ($F = 5.06$, $p < .01$). Thus the data apparently suggest a tradeoff in performance: As stimuli are changed from VV to AV to VS, subjects became progressively more likely to shift resources to the Sternberg task at the expense of tracking. The consequences of this shift, while performing the VS task because of its common resource demands with tracking is that there is a particularly large disruption of tracking error.

(B) INTERACTIONS WITH AGE. Figure R3 presents performance on the four versions of the single task Sternberg task at low memory load, and performance on second order tracking as a function of the four levels of age groups employed. Three factors are immediately apparent. (1) All tasks show a roughly monotonic decline in performance across age. (2) The trend is of a slightly different form for the RT tasks and tracking. The former show no loss in performance from Group 1 to 2; while for the tracking task this drop is significant. (3) AS shows no significant performance loss whatsoever ($F(3,56) = 1.51$, $p = .22$.

To investigate further whether these group differences were enhanced in some conditions relative to others, three ANOVAs were run: one on the single and dual task latency data for the two verbal versions of the Sternberg task (AV & VV), a second on the single and

0.38. Furthermore, tracking error is increased by the higher memory load ($F = 22.9$, $p < .001$), and the data indicate the opposite pattern of interference from that which was obtained for reaction time. That is, tracking error is now highest in the presence of the V-S memory search task, and nearly equivalent for the two verbal tasks, but slightly lower when the stimuli were visual ($F = 46.9$, $p < .001$). In addition, stimulus type and set size interact, with the increased memory load producing a greater effect on tracking performance when the stimuli are spatial than when they are verbal ($F = 5.06$, $p < .01$). Thus the data apparently suggest a tradeoff in performance: As stimuli are changed from VV to AV to VS, subjects became progressively more likely to shift resources to the Sternberg task at the expense of tracking. The consequences of this shift, while performing the VS task because of its common resource demands with tracking is that there is a particularly large disruption of tracking error.

(B) INTERACTIONS WITH AGE. Figure R3 presents performance on the four versions of the single task Sternberg task at low memory load, and performance on second order tracking as a function of the four levels of age groups employed. Three factors are immediately apparent. (1) All tasks show a roughly monotonic decline in performance across age. (2) The trend is of a slightly different form for the RT tasks and tracking. The former show no loss in performance from Group 1 to 2; while for the tracking task this drop is significant. (3) AS shows no significant performance loss whatsoever ($F(3,56) = 1.51$, $p = .22$.

To investigate further whether these group differences were enhanced in some conditions relative to others, three ANOVAs were run: one on the single and dual task latency data for the two <u>verbal</u> versions of the Sternberg task (AV & VV), a second on the single and

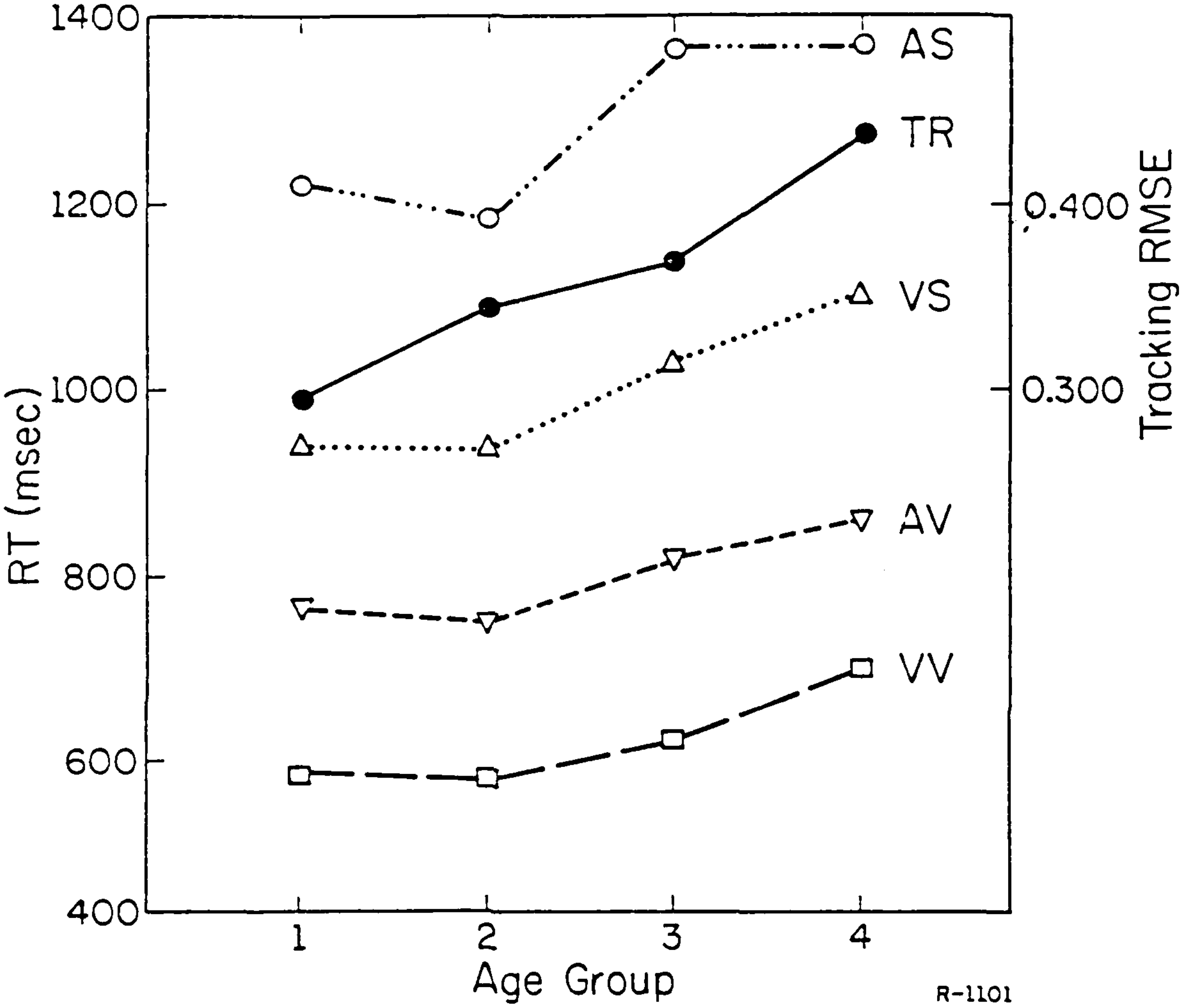


Figure R3: Age effects on Sternberg reaction time (low memory load) and single task tracking.

dual task latency data for the two visual versions of the RT task (VV & VS), and a third on the dual task tracking data using three levels of Sternberg type (AV, VV, & VS). All ANOVAs also included set size and, of course, age group as factors.

The most significant finding from these ANOVAs is the observation that age group did not interact with dual task loading; nor were these two factors involved in any higher order interactions in a manner that would imply that time-sharing efficiency deteriorates with age. All p values involving the age factor were greater than .10.

Correspondingly, the ANOVA of the dual task tracking data failed to reveal any age effects that were not evident in the single task data. The trends across the four groups were the same for all of the different Sternberg tasks. These trends are shown in Figure R4.

In fact, the data revealed few strong effects of age beyond the "general slowing" suggested in Figures R3 and R4. Two interactions provide minor exceptions: (1) As shown in Figure R5 the effect of increasing memory set size was slightly enhanced for the older two groups ($F = 2.9$, $p < .05$). In fact, however, the data indicate that this interaction is attributable primarily to the auditory data. The three way interaction of age x modality x set size was reliable ($F(3,56) = 3.45$, $p = .02$) and when this interaction was examined, the conclusion can be drawn that visual search rate is not slowed by age at all, while the auditory rate is slower for graph 3 and 4 than for 1 and 2.

(2) As shown in Figure R6, there is an interaction between age and stimulus type for the visual stimuli. Age produces a greater slowing of RT to the spatial than to the verbal stimuli ($F = 4.15$, $p < .01$). This difference is evidently independent of the presence or absence of

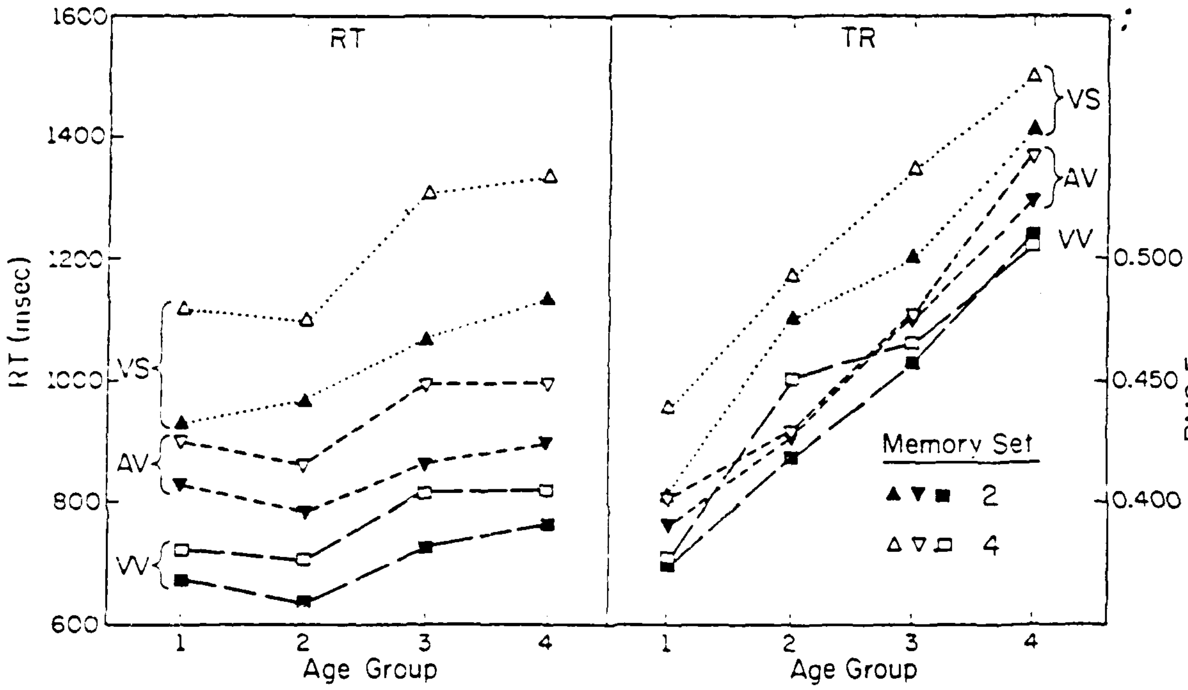


Figure R4: Dual task memory search latency (RT, left panel) and tracking error (right panel) as functions of age, stimulus type, and memory load.

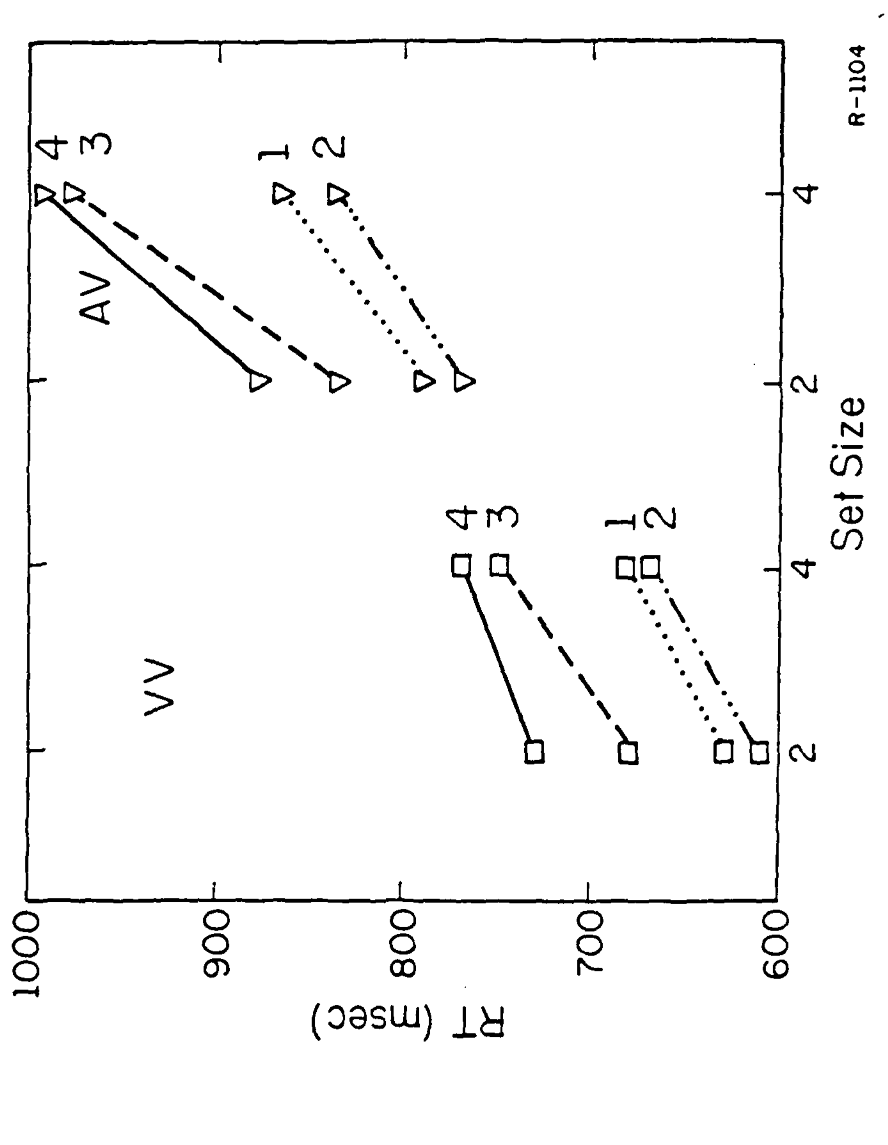


Figure R5. Verbal memory search RT as a function of set size, stimulus modality, and age group (1, 2, 3, or 4).

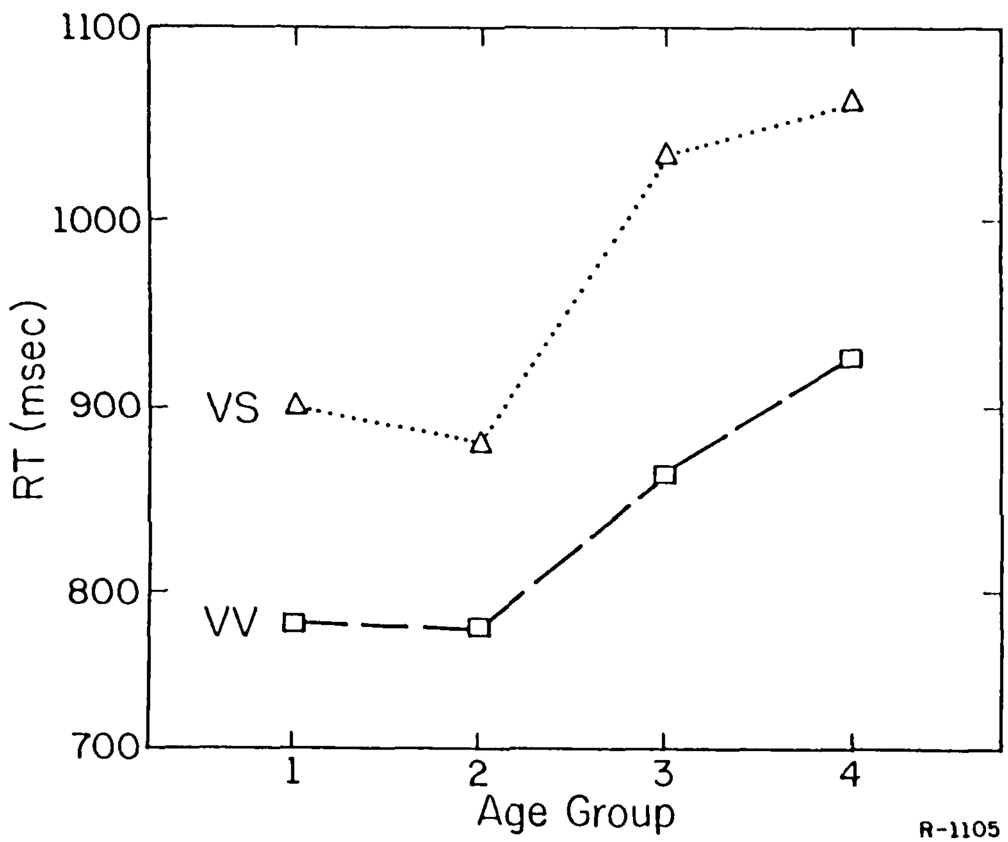


Figure R6: Visual memory search RT as a function of age group and stimulus code (verbal VV vs. spatial VS).

dual task loading, or the size of the memory set, since no higher order interactions were obtained.

Figure R7 shows the data across age groups for the remaining seven tasks: The delayed digit cancelling task (DDC) in both single and dual task conditions, along with tracking error when performed with the DDC task at the bottom; λ_c on the critical task in the middle, and the latency measures for the three spatial tasks at the top.

Examination of these data indicates (a) for single task DDC, there is a slight loss of accuracy ($F = 2.96$, $p < .04$), but no reliable change in latency. (b) In dual task conditions there is an enhanced effect of age on DDC accuracy, relative to single task conditions ($F = 6.19$, $p < .001$), but again there is no reliable latency effect ($p < .10$). (c) There is an increase in dual task tracking error with age that parallels the single task tracking function ($F = 8.09$, $p < .001$), but again is slightly enhanced. (d) There is a reliable decrease in performance on the critical tracking task ($F = 3.58$, $p < .02$). Mirroring the change in RT performance, this task shows no loss until the third age group. (e) Performance speed on the figure rotation task showes a monotonic, but non-reliable ($p > .10$) decrease with age, (f) response time in the hidden figures task showed a reliable age decrement ($F = 4.44$, $p < .01$). This was not attributable to a speed accuracy tradeoff as the error function, not shown in the figure, moved in a parallel direction ($p > .10$). This age trend shows the same profile as the speed measures of RT and the critical task measure. (g) The slowing of performance in the maze tracking task was also reliable ($F = 4.53$, $p < .01$) and, like second order tracking, showed the pronounced drop between groups 1 and 2. The error rate did not differ significantly between groups ($p > .10$). The results of the remaining

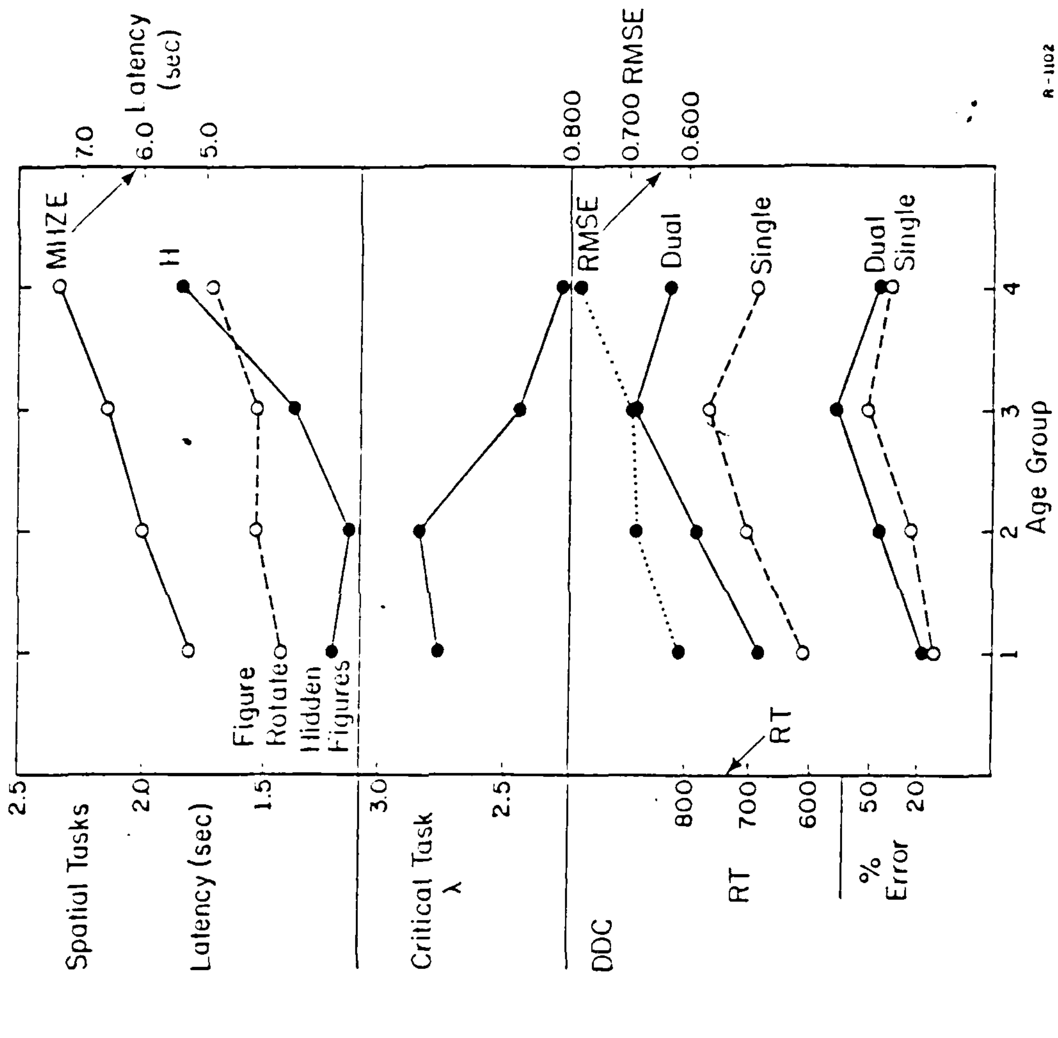


Figure R7: Performance as a function of age: (1) spatial task latencies (top), (2) critical task λ_c (middle), (3) delayed digit cancelling single and dual task performance (bottom).

battery item, dichotic listening task, will be discussed later.

(C) Correlational and factor analysis. Table 3 presents the correlation of Session 1 with Session 2 data for each task indicating the test-retest reliability measures. The reliabilities are not exceptional for the tracking and Sternberg tasks, but are considerably higher for the spatial tasks. For the RT tasks the latency measures have the highest reliability. Interestingly, for almost all tasks, the reliabilities in dual task conditions were considerably higher than in single task performance.

Table 4 shows the intercorrelations among all variables including the chronological age variable. Fifty of the fifty-one measures (excluding chronological gage) were submitted to a minimum residual factor analysis (Harman & Jones, 1966). A parallel analysis conducted on random data (Humphreys, Ilgen, McGrath, & Montanelli, 1969) indicated that the first four factors that could be extracted accounted for greater variance than would be expected by chance alone. Figure R8 plots the actual Eigenvalues of the different factors against the values that would be expected when the analysis is performed on random data. We have, in addition, included a fifth factor in our discussion and interpretation. Extracting a fifth factor helped us to minimize the factor intercorrelations and facilitated the interpretation.

Table 5 lists the five factors, their respective Eigenvalues, and the tasks that load on each. It is evident that the first factor, which we have labelled as perceptual-motor speed accounts for a very large proportion of the variance. The factor loads highest on the latency measures of all RT tasks, independent of modality, and central processing code. We make the direct association with speed here because of the considerably lower loadings that are found with the # correct measure. The latter is a total performance measure that includes both speed and accuracy. Hence, inclusion of variance in

TABLE 3.
INTERSESSION TASK CORRELATIONS
(Reliability Measures)

(SESSIONS 1 & 2)

SINGLE TASKS:

2nd-order Compensatory Tracking:		.64
Critical Tracking:		.39
Delayed Digit Recall:	# correct	.53
	RT	.62
Sternberg Short-Term Memory search:		
1. Visual-Verbal (2):	# correct	.19
	RT	.61
2. Visual-Verbal (4):	# correct	.20
	RT	.56
3. Auditory-Verbal (2):	# correct	.17
	RT	.53
4. Auditory-Verbal (4):	# correct	.17
	RT	.64
5. Visual-Spatial (2):	# correct	.32
	RT	.60
6. Visual-Spatial (4):	# correct	.25
	RT	.55
7. Auditory-Spatial (2):	# correct	.32
	RT	.47
Figure Rotation:	# correct	.70
	RT	.85
Hidden Figures:	# correct	.91
	RT	.79
Maze Tracing:	# correct	.75
	RT	.83

DUAL TASKS

1. Visual-Verbal (2) + 2nd-order tracking:	# correct	.31
	RT	.77
	RMS	.82
2. Visual-Verbal (4) + 2nd-order tracking:	# correct	.18
	RT	.77
	RMS	.85
3. Auditory-Verbal (2) + 2nd-order tracking:	# correct	.19
	RT	.60
	RMS	.86
4. Auditory-Verbal (4) + 2nd-order tracking:	# correct	.21
	RT	.72
	RMS	.85
5. Visual-Spatial (2) + 2nd-order tracking:	# correct	.32
	RT	.57
	RMS	.86
6. Visual-Spatial (4) + 2nd-order tracking:	# correct	.24
	RT	.54
	RMS	.81
7. Delayed Digit Recall + 2nd-order tracking:	# correct	.70
	RT	.67
	RMS	.86
Dichotic Listening Task:		
1. Omissions:	# correct	.93
2. Intrusions:	# correct	.89
3. Incomplete:	# correct	.36
4. Mixed:	# correct	.60
5. Incorrect Ear:	# correct	.64

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. AGE	1.00																
2. 2nd ORDER TRACKING	.46	1.00															
3. CRITICAL TRACKING	.44	.64	1.00														
4. DELAYED D. RECALL C	-.31	-.42	-.42	1.00													
5. RT	.13	.18	.16	-.47	1.00												
6. STERNBERG VV2 C	-.17	-.25	-.14	.03	-.26	1.00											
7. RT	.45	.49	.36	-.11	.07	-.25	1.00										
8. VV4 C	-.12	-.21	.03	.07	-.16	.00	.13	1.00									
9. RT	.43	.38	.21	-.16	-.01	.01	.66	-.44	1.00								
10. AV2 C	-.22	-.12	-.13	.15	-.23	.22	-.31	.15	-.29	1.00							
11. RT	.45	.40	.17	-.12	.11	-.15	.71	-.13	.70	-.43	1.00						
12. AV4 C	-.26	-.17	-.21	.25	-.09	.22	-.06	-.11	-.19	.17	-.14	1.00					
13. RT	.38	.35	.21	-.11	.05	-.12	.57	-.19	.70	-.28	.73	-.47	1.00				
14. VS2 C	-.30	-.40	-.23	.26	-.06	.04	-.23	.12	-.38	.26	-.46	.29	-.47	1.00			
15. RT	.36	.44	.25	-.28	.13	-.10	.57	-.05	.53	-.37	.64	-.28	.60	-.61	1.00		
16. VS4 C	-.18	-.05	-.06	.15	-.08	.00	-.33	.19	-.31	.27	-.43	-.06	-.24	.35	-.31	1.00	
17. RT	.34	.29	.19	-.06	-.07	-.07	.53	-.10	.62	-.37	.72	-.08	.55	-.39	.54	-.59	1.00
18. AS2 C	-.18	-.30	-.07	.05	-.08	.24	-.28	.16	-.30	.24	-.35	.16	-.22	.21	-.31	.03	-.28
19. RT	.22	.26	.06	.01	.11	-.27	.52	-.12	.42	-.29	.55	-.16	.48	-.21	.47	-.04	.49
20. FIGURE ROTATION C	-.32	-.50	-.25	.05	-.01	.32	-.46	.05	-.34	.28	-.39	.34	-.30	.37	-.47	.23	-.37
21. RT	.25	.45	.16	-.09	.06	-.23	.45	-.14	.46	-.21	.47	-.16	.42	-.31	.48	-.21	.50
22. HIDDEN FIGURES C	-.44	-.49	-.26	.23	-.19	.07	-.45	.07	-.55	.32	-.54	.28	-.48	.43	-.62	.29	-.53
23. RT	.34	.45	.29	-.17	.11	-.12	.46	-.02	.53	-.32	.46	-.19	.60	-.32	.60	-.24	.52
24. MAZE TRACING C	-.39	-.35	-.16	.01	-.08	.38	-.35	.03	-.26	.21	-.32	.17	-.22	.13	-.20	.14	-.36
25. RT	.42	.36	.19	-.13	.03	-.30	.43	.01	.31	-.21	.47	-.25	.39	-.27	.38	-.27	.41
26. DUAL TASKS VV2 C	-.04	-.14	-.04	.23	-.15	.00	-.11	-.09	.06	.05	-.17	.24	-.08	.16	-.22	.28	-.08
27. RT	.42	.41	.26	-.11	-.03	-.03	.59	-.09	.57	-.23	.71	-.20	.65	-.32	.53	-.26	.52
28. RMS	.38	.84	.62	-.44	.28	-.18	.37	-.20	.42	-.11	.35	-.15	.32	-.33	.35	-.03	.28
29. VV4 C	-.12	-.06	-.07	.09	.11	.24	-.10	.16	-.17	.14	-.19	.09	-.09	.38	-.25	.23	-.16
30. RT	.43	.48	.33	-.13	-.00	-.11	.65	-.22	.56	-.27	.70	-.21	.64	-.30	.67	-.36	.49
31. RMS	.41	.82	.65	-.41	.23	-.20	.39	-.16	.41	-.16	.34	-.24	.33	-.37	.36	-.04	.24
32. AV2 C	-.20	-.22	-.15	.08	-.20	-.12	-.45	.12	-.46	.00	-.40	.08	-.39	.11	-.36	.08	-.22
33. RT	.28	.30	.24	-.06	.25	-.11	.53	-.11	.62	-.10	.61	-.12	.58	-.21	.42	-.15	.36
34. RMS	.40	.80	.63	-.37	.25	-.26	.39	-.12	.37	-.07	.36	-.24	.36	-.36	.32	.02	.24
35. AV4 C	-.12	-.17	.01	-.14	.09	.20	-.20	.25	-.37	.05	-.35	.13	-.33	.04	-.23	.18	-.39
36. RT	.27	.36	.13	.02	-.01	-.00	.57	-.08	.55	-.23	.67	-.23	.60	-.31	.50	-.13	.39
37. RMS	.37	.80	.59	-.38	.25	-.23	.39	-.11	.35	-.16	.37	-.19	.33	-.36	.34	.01	.24
VS2 C	-.31	-.19	-.05	.19	.03	-.02	-.23	.00	-.34	.21	-.39	.23	-.33	.20	-.27	.29	-.44
RT	.46	.30	.24	-.08	-.04	.07	.40	-.05	.49	-.27	.57	-.14	.44	-.32	.63	-.11	.51
RMS	.38	.81	.56	-.38	.29	-.23	.39	-.20	.34	-.16	.40	-.09	.27	-.34	.31	-.02	.24
VS4 C	-.04	-.12	.04	.01	.12	-.11	-.24	-.01	-.27	.08	-.32	.18	-.31	.19	-.24	.21	-.24
RT	.41	.33	.19	-.09	-.01	-.10	.66	.01	.46	-.33	.59	-.35	.56	-.26	.55	-.14	.57
RMS	.42	.78	.57	-.37	.29	-.25	.40	-.22	.40	-.21	.38	-.15	.30	-.29	.32	-.01	.23
DDR C	-.35	-.44	-.39	.71	-.37	.05	-.25	.05	-.18	.15	-.23	.19	-.22	.23	-.42	.24	-.29
RT	.27	.38	.36	-.29	.60	-.04	.28	-.10	.12	-.27	.36	-.03	.29	-.29	.30	-.32	.27
RMS	.52	.65	.46	-.30	.19	-.25	.37	-.23	.45	-.29	.44	-.21	.35	-.31	.36	.03	.30
DLT: OMISSIONS	-.40	-.12	-.05	.04	.08	-.10	-.16	.36	-.52	.09	-.27	.11	-.42	.41	-.23	.19	-.24
INTRUSIONS	-.63	-.63	-.23	.22	-.01	.25	-.27	.05	-.18	.00	-.22	.09	-.28	.22	-.22	.24	-.37
INCOMPLETE	-.16	.01	.08	-.05	.20	.03	-.11	.28	-.29	-.11	-.16	-.03	-.18	.26	-.17	.28	-.23
MIXED	-.17	-.22	-.13	.09	-.01	.14	.06	-.03	.06	.08	-.02	.16	-.11	.10	.07	.03	-.07
INCORRECT EAR	-.25	-.28	-.48	.34	-.12	.12	-.10	-.26	-.02	.07	-.18	.22	-.16	.39	-.28	.21	-.31

	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
18. AS2 C	1.00																
19. RT	-.70	1.00															
20. FIGURE ROTATION C	.31	-.38	1.00														
21. RT	-.41	.53	-.65	1.00													
22. HIDDEN FIGURES C	.30	-.32	.54	-.51	1.00												
23. RT	-.36	.31	-.55	.55	-.92	1.00											
24. MAZE TRACING C	.38	-.38	.49	-.45	.36	-.32	1.00										
25. RT	-.34	.63	-.57	.64	-.43	.41	-.70	1.00									
26. DUAL TASKS VV2 C	.11	-.01	.11	-.21	.13	-.09	.08	-.11	1.00								
27. RT	-.43	.40	-.19	.29	-.47	.44	-.28	.37	-.30	1.00							
28. RMS	-.35	.25	-.34	.38	-.46	.45	-.39	.27	-.14	.41	1.00						
29. VV4 C	.20	-.10	.06	.01	.06	-.07	-.12	-.04	.16	-.35	.00	1.00					
30. RT	-.39	.37	-.27	.33	-.43	.38	-.27	.42	-.26	.87	.41	-.34	1.00				
31. RMS	-.39	.25	-.43	.34	-.47	.46	-.41	.30	-.16	.38	.94	-.04	.43	1.00			
32. AV2 C	.18	-.40	.06	-.20	.30	-.26	-.05	-.16	.05	-.49	-.12	.20	-.52	-.07	1.00		
33. RT	-.23	.45	-.09	.25	-.36	.31	-.16	.32	-.17	.72	.28	-.23	.70	.20	-.76	1.00	
34. RMS	-.33	.26	-.29	.26	-.41	.40	-.38	.25	-.14	.40	.91	.00	.43	.92	-.15	.35	1.00
35. AV4 C	.35	-.14	.13	-.20	.26	-.36	.08	-.04	.09	-.43	-.15	.21	-.44	-.15	.12	-.27	-.15
36. RT	-.43	.40	-.23	.35	-.42	.43	-.21	.31	-.19	.79	.28	-.23	.79	.28	-.58	.66	.31
37. RMS	-.37	.27	-.34	.27	-.40	.40	-.36	.23	-.12	.37	.92	.04	.42	.96	-.10	.28	.95
VS2 C	.15	-.09	.22	-.33	.34	-.28	.16	-.26	.14	-.38	-.04	.24	-.38	-.04	.17	-.12	-.02
RT	-.26	.36	-.28	.35	-.50	.48	-.09	.22	-.11	.57	.27	-.31	.48	.24	-.44	.42	.23
RMS	-.37	.27	-.35	.26	-.40	.36	-.37	.20	-.13	.35	.92	-.02	.41	.92	-.08	.24	.91
VS4 C	.27	-.22	.22	-.31	.34	-.31	.16	-.36	.30	-.56	-.18	.21	-.48	-.16	.27	-.31	-.08
RT	-.35	.46	-.27	.37	-.54	.53	-.26	.44	-.25	.76	.31	-.30	.66	.30	-.46	.57	.30
RMS	-.36	.25	-.32	.24	-.44	.42	-.42	.22	-.07	.37	.92	.04	.42	.92	-.07	.25	.91
DDR C	.08	-.07	.02	-.12	.26	-.22	.08	-.11	.29	-.31	-.45	.14	-.24	-.34	.17	-.27	-.34
RT	-.32	.17	-.26	.15	-.45	.32	-.26	.28	-.08	.29	.40	.06	.31	.40	-.27	.42	.38
RMS	-.27	.28	-.36	.36	-.36	.36	-.45	.32	.03	.34	.74	.04	.39	.72	-.08	.20	.70
DLT: OMISSIONS	.18	-.12	.01	-.17	.26	-.17	.26	-.19	-.09	-.36	-.18	.14	-.30	-.15	.23	-.25	-.15
INTRUSIONS	.18	-.15	.24	-.30	.27	-.25	.38	-.31	.29	-.31	-.33	-.03	-.28	-.30	-.06	-.18	-.37
INCOMPLETE	.20	-.09	.00	-.11	.12	-.06	.09	-.05	-.04	-.24	.09	.34	-.23	.09	.09	-.10	.11
MIXED	.09	-.03	-.02	.03	.11	.00	.25	-.14	.00	-.15	-.17	-.06	-.07	-.14	-.08	-.12	-.18
INCORRECT EAR	.20	-.12	.26	-.31	.44	-.51	.27	-.41	.30	-.23	-.23	.09	-.22	-.29	.00	-.16	-.22

	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
35. AV4 C	1.00															
36. RT	-.31	1.00														
37. RMS	-.14	.31	1.00													
VS2 C	.25	-.40	-.03	1.00												
RT	-.23	.49	.27	-.37	1.00											
RMS	-.11	.26	.95	-.08	.30	1.00										
VS4 C	.25	-.47	-.05	.28	-.26	-.05	1.00									
RT	-.36	.67	.29	-.46	.66	.24	-.62	1.00								
RMS	-.19	.28	.94	-.04	.27	.95	-.11	.31	1.00							
DDR C	.01	-.08	-.36	.27	-.26	-.35	.01	-.29	-.35	1.00						
RT	-.04	.23	.39	-.16	.18	.40	-.18	.24	.40	-.45	1.00					
RMS	-.10	.25	.71	-.04	.32	.76	-.07	.30	.79	-.18	.18	1.00				
DLT: OMISSIONS	.07	-.26	-.12	.19	-.33	-.12	.07	-.16	-.13	.03	-.01	-.25	1.00			
INTRUSIONS	.15	-.03	-.30	.09	-.05	-.27	-.01	-.14	-.24	.31	-.09	-.20	.39	1.00		
INCOMPLETE	.28	-.14	.15	.17	-.20	.11	.04	-.06	.12	-.09	.14	.09	.57	.33	1.00	
MIXED	-.06	-.08	-.14	.02	.10	-.13	-.06	.02	-.14	.14	-.16	-.10	.36	.50	.13	1.00
INCORRECT EAR	.10	-.11	-.20	.17	-.19	-.19	.12	-.21	-.20	.31	-.28	-.15	.06	.33	.02	.27

Table 4

Intercorrelations for all single and dual task measures including age. ($p = .05$, $r = .214$)

FIGURE R8: PARALLEL ANALYSIS FOR [illegible]TIVE PERFORMANCE DATA
AUGUST 1, 1983

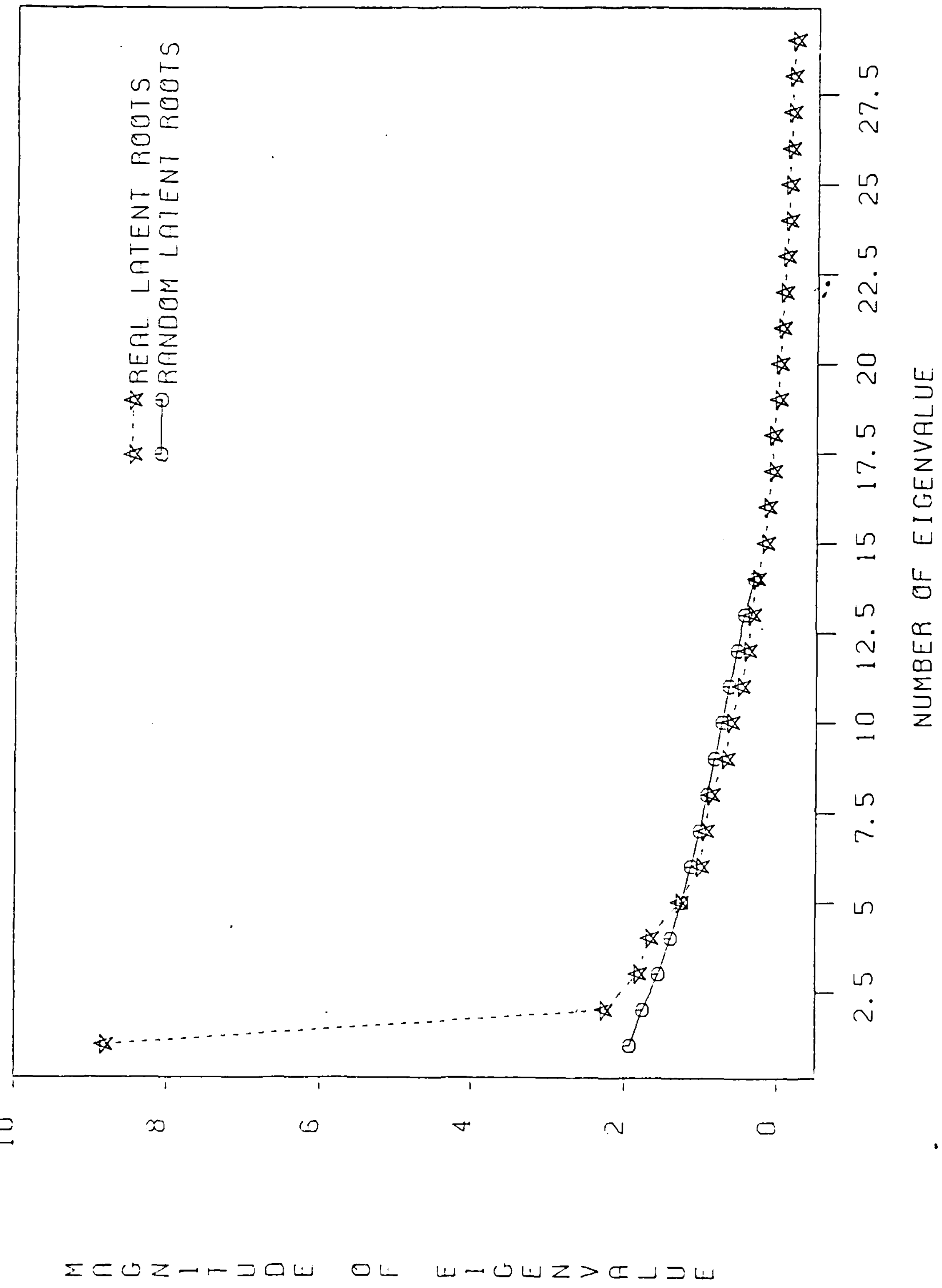


TABLE 5. ROTATED FACTOR PATTERN LOADINGS (SINGLE TASKS SOLUTION)*

		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1. 2nd-order Compensatory Tracking:			.63		.34	
2. Critical Tracking:			.64			
3. Delayed Digit Recall:	number correct		.72			
	RT		.55			
Sternberg Short-Term Memory Search:						
4. Visual-Verbal (2):	number correct				.56	
	RT	.63			.39	
5. Visual-Verbal (4):	number correct					-.55
	RT	.79				-.33
6. Auditory-Verbal (2):	number correct	.38				
	RT	.78				
7. Auditory-Verbal (4):	number correct		.37			
	RT	.67				
8. Visual-Spatial (2):	number correct	.53				
	RT	.74				
9. Visual-Spatial (4):	number correct	.54				
	RT	.76				
10. Auditory-Spatial (2):	number correct				.61	
	RT	.39			.70	
11. Figure Rotation:	number correct	.44			.53	
	RT	.49			.55	
12. Hidden Figures:	number correct	.71				.33
	RT	.69				.41
13. Maze Tracing:	number correct				.68	
	RT	.34			.62	
Dichotic Listening Task:						
14. Omissions:	number correct	.32		.74		
15. Intrusions:	number correct			.63		
16. Incomplete:	number correct			.60		
17. Mixed:	number correct			.58		
18. Incorrect Ear:	number correct		.34			.64
Percent Variance accounted for after rotation:		21	9	8	12	6

accuracy seems to "dilute" the loadings somewhat. In a separate factor analysis run in which % correct was included as a variable, this variable loaded on a separate factor from the latency data.

Factor 2 we label perceptual motor coordination, although the motor factor may be the more important defining characteristic. The factor loads high on both tracking tasks and the delayed digit cancelling task which itself entails a fair degree of manual dexterity. The loadings of this factor on the remaining two tasks: AV4 # correct and one of the switching measure of the dichotic listening task while lower, are also reliable and lead us to broaden the description of the task from one of pure manual dexterity, to one related to flexibility.

Factor 3 loads only on the dichotic listening task. The two focusing measures and two of the three measures of switching. The factor clearly appears to relate to some aspect of attention, but whether this is focussing or switching cannot be determined.

Factor 4 seems to be a spatial abilities factor loading on figure rotation and maze tracking as well as the auditory-spatial Sternberg task. Interestingly, this factor also loads on second order tracking, but not on the critical tracking task, indicating the greater spatial demands of the former task. The loadings for the spatial factor on the VV2 task are not readily interpretable, although it should be noted that here, unlike factor 2, the # correct measure, assessing speed <u>and</u> accuracy, loads higher than does the pure speed measure.

Finally, the fifth factor, although not technically warranted for consideration from the parallel analysis is somewhat unique in loading on the embedded figures test and the incorrect ear measure of dichotic listening. It is possible that this represents the "field dependence" measure of cognitive ability, although this clearly accounts for only a very small proportion of the variance.

Altogether the five factors accounted for 56% of the total single task variance. Employing Dwyer's extention (Dwyer, 1937), the dual task correlations were entered into the same factor structure as the single, to determine how well the single task pattern of abilities could account for time-shared performance of the same tasks. If the accounting is high, then there is no reason to assume that individual differences in dual task abilities are any different than those underlying the single task components. The data in Table 6 indicate that considerably less variance is accounted for (40.3%) than by the single task structure (56%). Comparing the individual loadings it is apparent that a large drop from single to dual task occurs in the loading for the latency measure of the RT tasks, indicating that variance in time-sharing ability may be reflected in these measures.

In order to provide an estimate of how the various factors changed with age, we have correlated the factor scores of each individual on each factor with age. These plots are shown in Figure R9a-e, and show an ordering that corresponds reasonably well with the interpretations drawn in Section A. Factor 1, related to general perceptual-motor speed shows the strongest rate of decline, followed by Factor 2 related to perceptual-motor coordination and manual dexterity. It should be noted that of the tasks that load on this second factor, the two tracking tasks correlated reliably with age ($r = .40$ & $-.30$ for second order error and critical task λ), while the dichotic listening measure shows almost no trend ($r = .14$). These findings coincide with the observation in Figure R1 that both Sternberg and tracking measures should decline with age.

Factor 3, which is defined by dichotic listening ability shows a

Table 6. ESTIMATES OF NEW FACTOR LOADINGS (Dual Tasks Extension)*

		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1. Visual-Verbal (2):	number correct	.12				
	RT	.59				
	RMS		.66			
2. Visual-Verbal (4):	number correct					
	RT	.58				
	RMS		.65		.32	
3. Auditory-Verbal (2):	number correct	.41				
	RT	.44				
	RMS		.66		.32	
4. Auditory-Verbal (4):	number correct	.33				
	RT	.60				
	RMS		.64		.32	
5. Visual-Spatial (2):	number correct	.43				
	RT	.64				
	RMS		.62		.32	
6. Visual-Spatial (4):	number correct	.38				
	RT	.58				
	RMS		.64		.32	
7. Delayed Digit Recall:	number correct		.66			
	RT		.49			
	RMS				.36	
Percent variance accounted for after rotation:		15	17	1.7	5.3	1.3

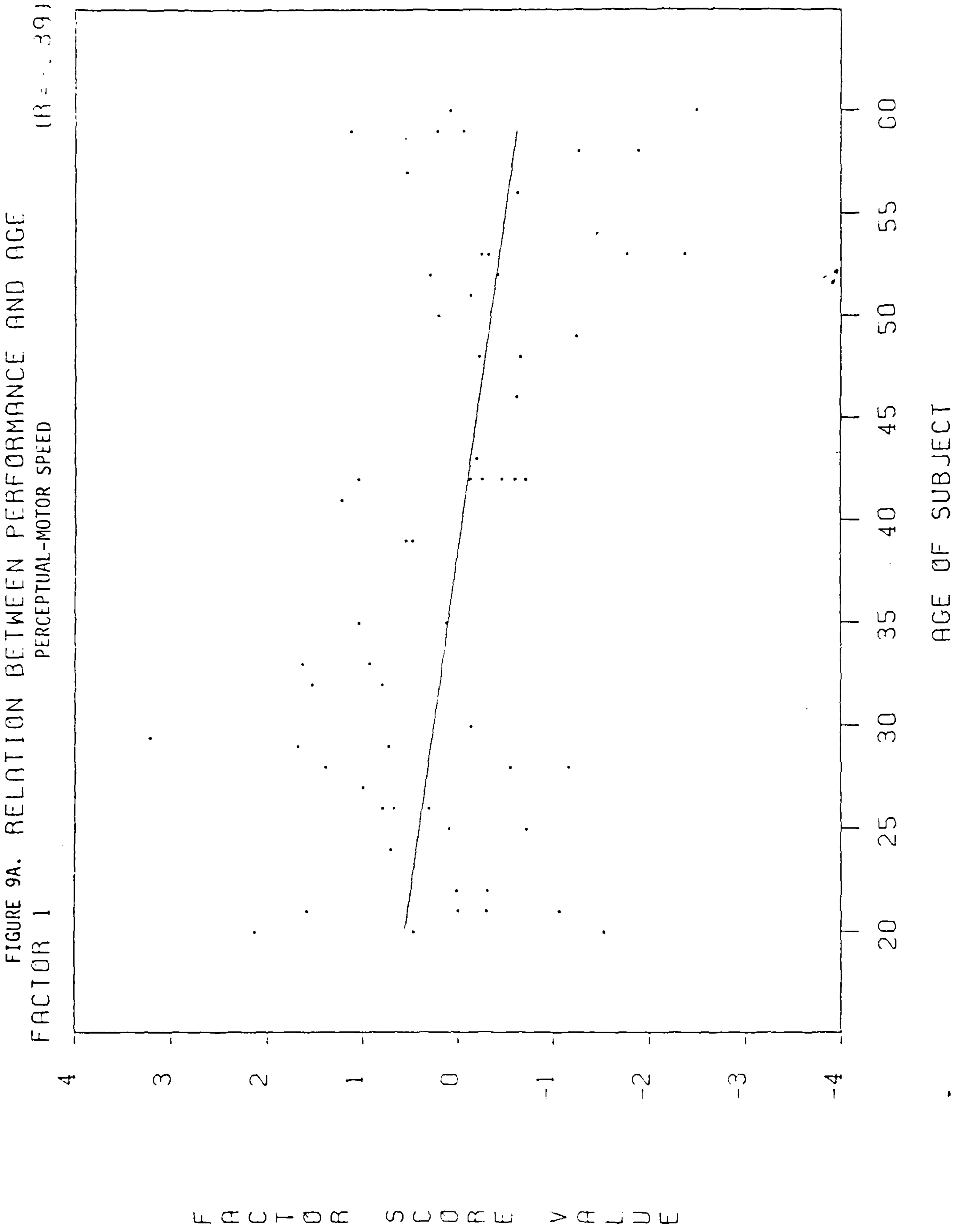


FIGURE 9A. RELATION BETWEEN PERFORMANCE AND AGE
(R = -.39)
FACTOR 1
PERCEPTUAL-MOTOR SPEED
4
3
2
1
0
-1
-2
-3
-4
FACTOR SCORE VALUE
20
25
30
35
40
45
50
55
60
AGE OF SUBJECT

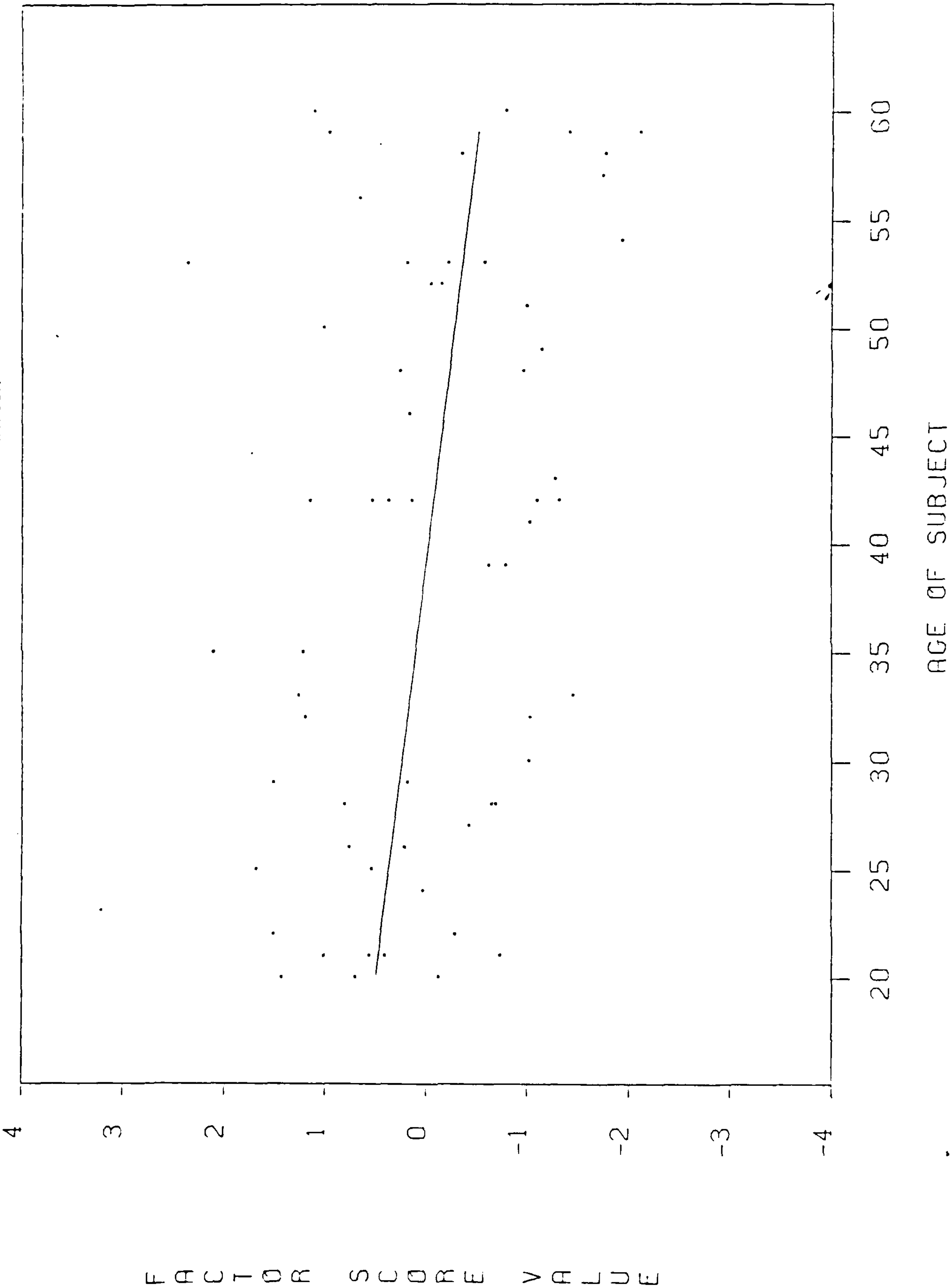


FIGURE 9B. RELATION BETWEEN PERFORMANCE AND AGE
FACTOR 2 PERCEPTUAL MOTOR COORDINATION (R = -.32)

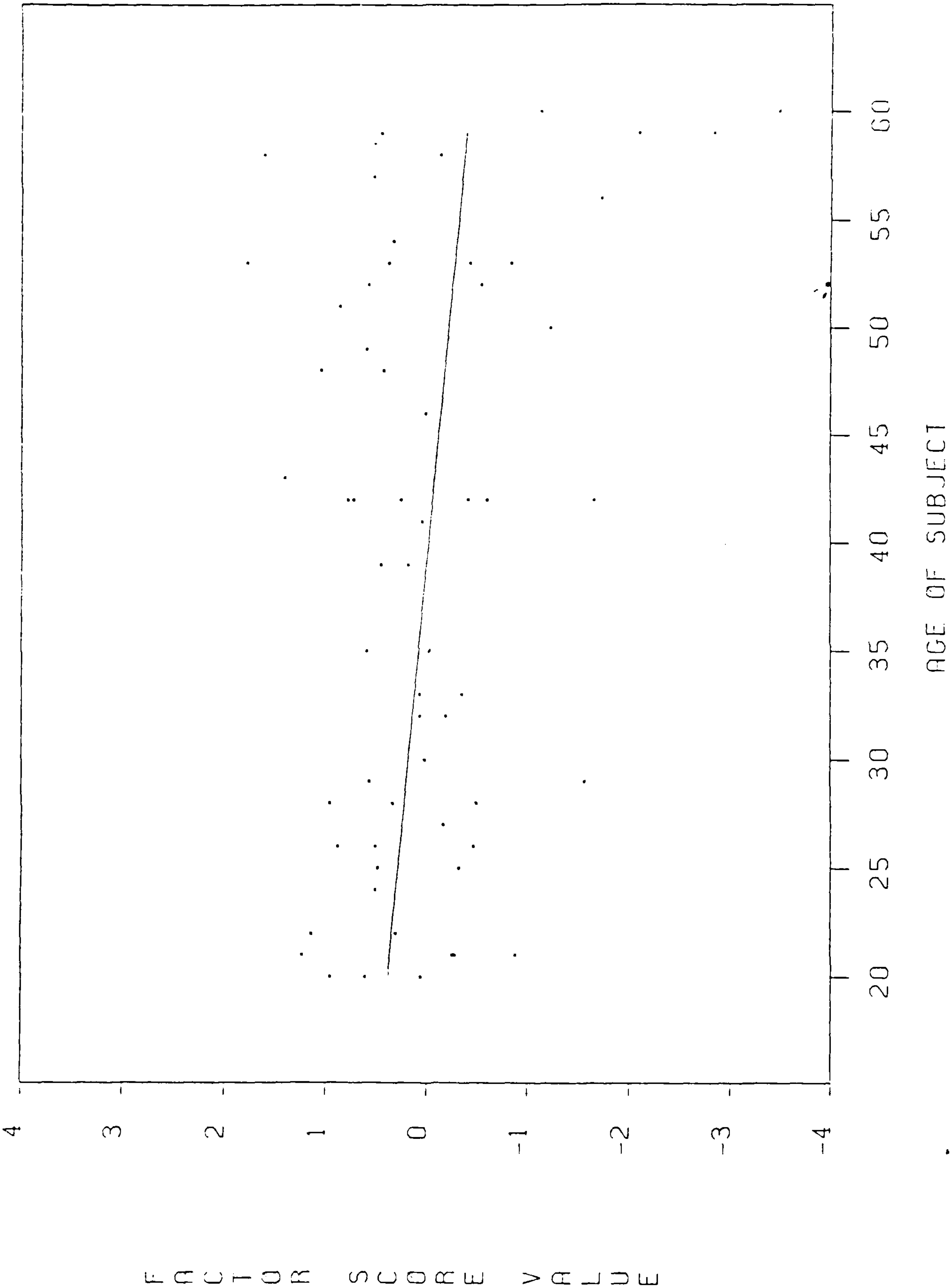


FIGURE 9C. RELATION BETWEEN PERFORMANCE AND AGE
FACTOR 3 DICHOTIC LISTENING (R = -.26)

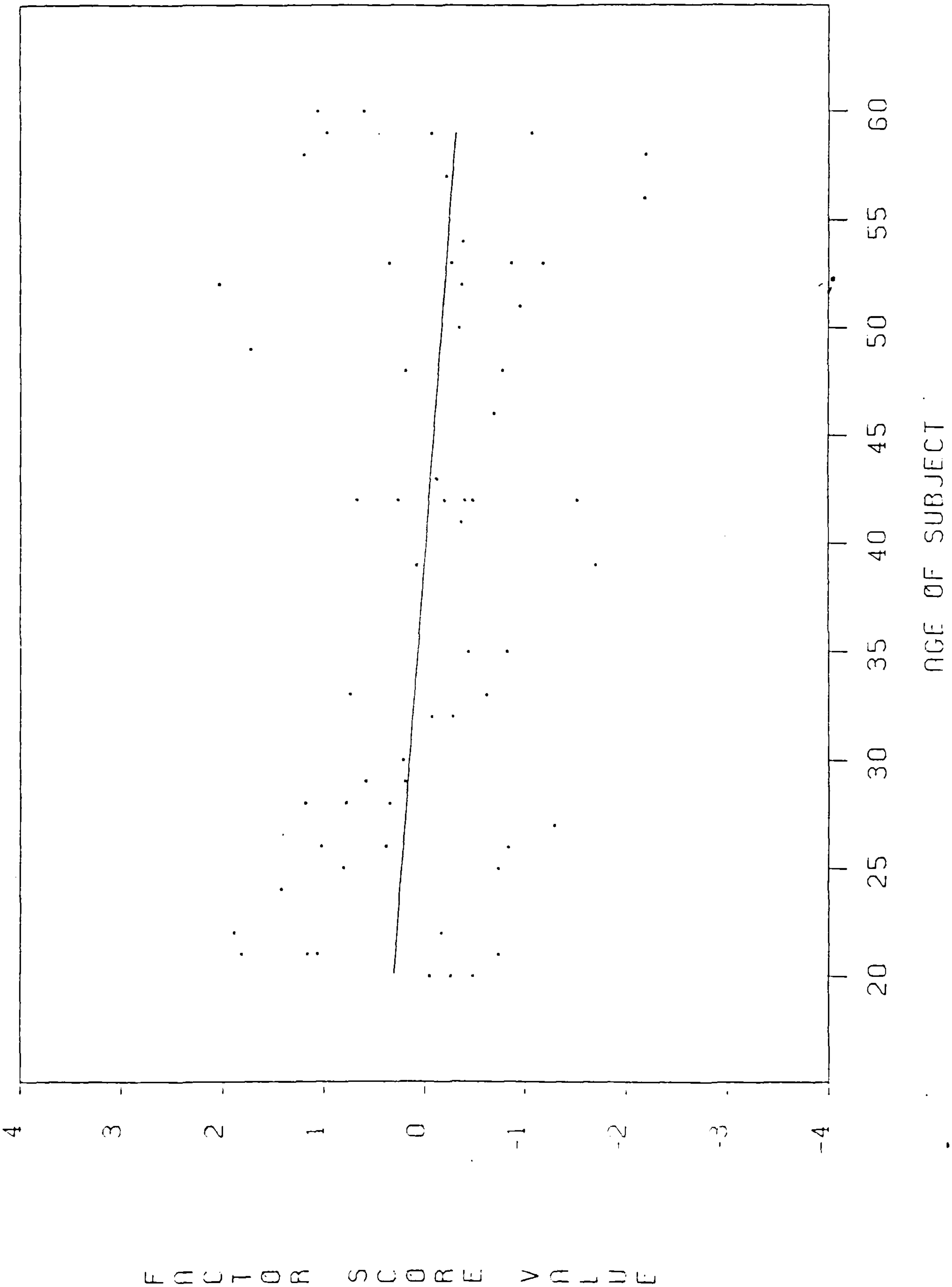
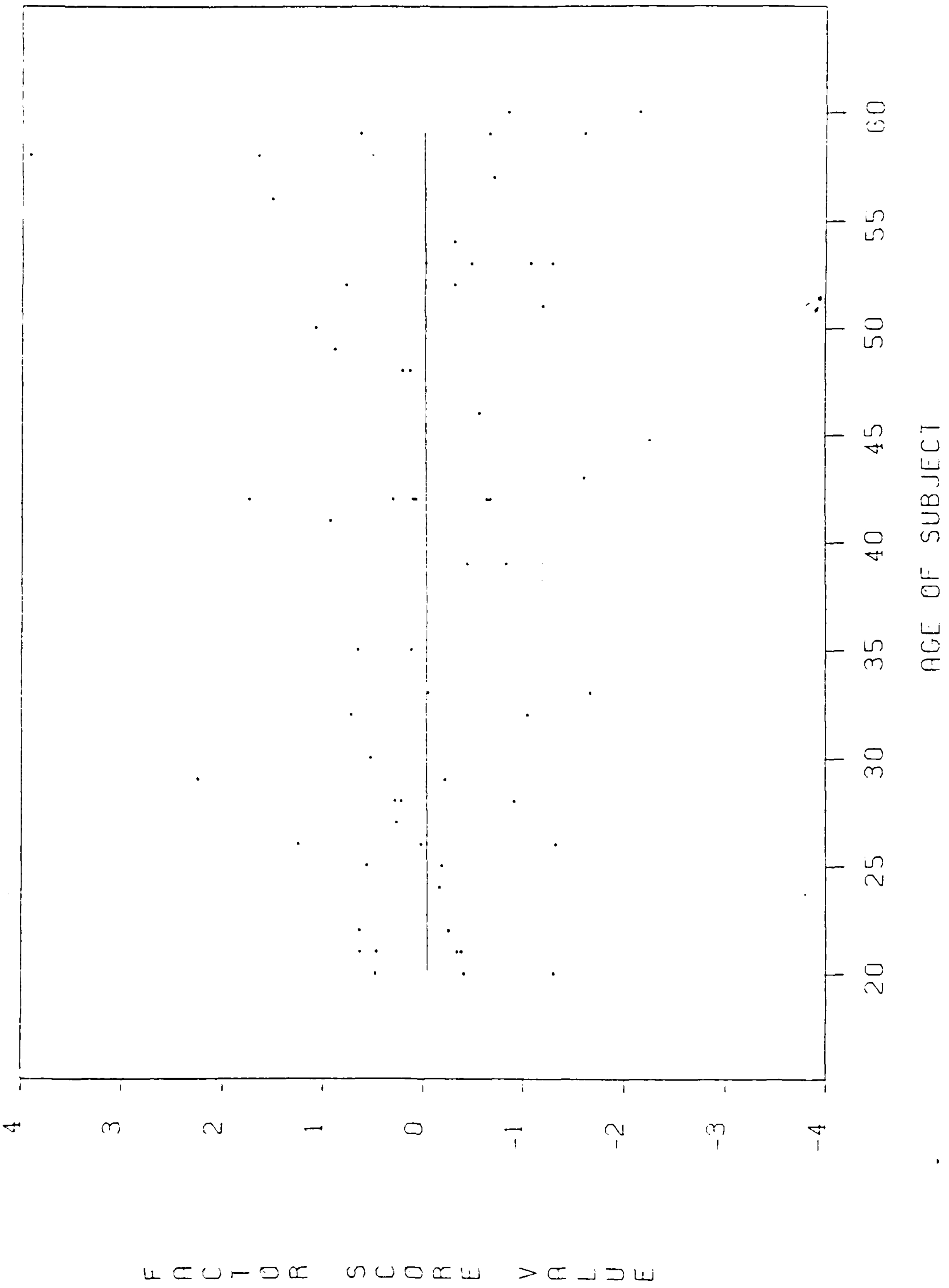


FIGURE 9D. RELATION BETWEEN PERFORMANCE AND AGE
FACTOR 4 SPATIAL ABILITY (R=-.22)

FIGURE 9E. RELATION BETWEEN PERFORMANCE AND AGE
FACTOR 5 FIELD DEPENDENCE/INDEPENDENCE (R=.02)



modest drop, although inspection of the figure indicates that this effect may be heavily dependent on the three points at the very oldest level. Factor 4, defining spatial ability, shows a slight trend, but the amount of variance in this score accounted for by age--only 4%--suggests that it is not significantly influenced. Factor 5 shows essentially no correlation with age.

In spite of the general age trends that are observed with the first three factors, attention should be called to the phenomenon noted in most aging research that there remains far more performance variance within an age group than between.

Dichotic listening task. The dichotic listening task was purported to assess two characteristics of attention: focusing (the part I measures of omissions and intrusions), and switching (the three part 2 measures). Table 7 indicates that all five measures decreased with age. The changes in the first four were statistically reliable, while the fifth measure (digits reported in the incorrect ear after the command is given to switch), was not. The factor analysis too revealed that the first four measures "belong" together, as all clustered on the common factor 3, while the fifth measure loaded on factor 2 (perceptual and motor coordination).

The reason why the fifth dichotic measure behaves differently from the third and fourth, all three of which are assumed to measure behavior related to attention switching, is not totally clear. One possibility is that this dissociation relates to the instability of the fifth measure. Its mean value was extremely small (< 1% for group 1), and for all groups the standard deviation was considerably greater than the mean, suggesting a high degree of positive skew.

While the five dichotic measures were all related to attention,

DICHOTIC LISTENING TASK

VARIABLE	G 1	G 2	G 3	G 4	p
Part 1					
% OMISSIONS	6.9	7.03	8.9	19.25	.01
% INTRUSIONS	1.17	2.89	2.77	6.24	.003
Part 2					
% INCOMPLETE	1.38	.83	1.66	4.30	.02
% MIXED	6.10	11.38	12.63	14.99	.05
% INCORRECT EAR	.41	1.66	2.49	3.05	.41

Table 7: Error scores (%) for the Dichotic Listening Task.

there is little strong evidence that they were related to time-sharing, at least as time-sharing was deployed by subjects in this study. First, the dichotic measures changed with age, but as noted above, there was little evidence for age-related changes in time-sharing ability. The exception of course is the fifth dichotic measure which, as noted showed no age effect. However, the correlations of this measure with dual task performance were no higher than with single task suggesting the absence of any relation to time-sharing. Second, while the four dichotic measures clearly define a separate factor, when the dual task Dwyer extention of the factor analysis was run, none of the dual task performance measures showed any loading on the dichotic listening factor. Finally, there was no evidence that the correlations of any of the dichotic measures with the 3 DDR measures (% correct, RT, TR error) are increased under dual as opposed to single task conditions. All of the measures remain fairly low.

Discussion

Although a large number of different tasks and task combinations were employed in the present study, the results appear to be reasonably orderly and can be represented in terms of a few basic trends. Specifically, it appears that there are three qualitatively different kinds of age trends in the data, each with different implications for generalization to the airborne environment. These categories are defined by:

(1) Abilities that show a decline across all age groups (some spatial and abilities perceptual-motor coordination);

(2) Abilities that show a decline beyond age 40 (speed),

(3) Abilities that do not appear to decline with age (time-sharing).

Each of these three clusters of effects will be treated in considerably more detail.

SPATIAL SKILLS AND PERCEPTUAL MOTOR COORDINATION. Second order tracking, DDR performance (as measured by error rate, but not speed), as well as latency of the maze tracing task and the two focussed attention measures of the dichotic listening task all show reliable declines with age that include differences between the two youngest groups. (While these were not tested with planned comparisons, it is apparent from Figures R3, R4, and R7 that they are of equal magnitude to the differences between older age groups). The common trend of these effects is butressed by the fact that the particular tasks also "clustered" together in the factor analysis (indeed the common pattern of variance across age may well have been partly responsible for the tasks belonging to common factors). Thus the second order tracking task and delayed digit recall both belonged to factor 2 and the DDR task loaded more strongly on this factor with the accuracy than with the latency variable. The two focused attention measures both loaded on factor 3, while the maze tracing task and second order tracking loaded on the fourth "spatial abilities" factor.

Perceptual speed. The second cluster of abilities relates to pure speed. Here we find that all of the Sternberg tasks (excluding AS) show a relatively common "J" shaped profile with roughly equal performance obtained between the first and second decades and a monotonic decline thereafter (Figures R3, R4, and R6). This profile is shared as well by the critical tracking task, well established also to serve as a measure of perceptual- motor speed (Jex, McDonnel, & Phatak, 1966; Allen, Clement, & Jex, 1970), and by the latency measure of hidden figures (Figure R7). These values are short enough to fall within the range of RTs of the Sternberg tasks. An exception to the J shaped pattern of RT tasks was found for the AS version of the Sternberg task which showed no reliable change in performance across any group, thus clustering it with the third set of variables to be discussed below.

The finding of a general slowing of processing time with age is not new (e.g., Salthouse & Sonberg, 1982), although the particular profile with age, and the association of tracking in the Critical Task with the speed component represents an important addition to the data base. While our data fail to reflect differences across the first two age groups, this does not suggest that such differences are entirely absent. Indeed, other investigators have obtained reliable effects in RT tasks across this age range. However, we believe that these effects are probably sufficiently small as to be insignificant when making generalizations to the flight environment.

The more precise nature of the components of slowing were suggested in Figures R5 and R6. Here the data indicated greater slowing when set size was high than low, indicating a decrease in the speed of short term memory search, an effect observed by other investigators (Salthouse & Sonberg, 1982). However, the interaction plotted in Figure R5 indicates that this slowing is only observed in the auditory modality. The interaction plotted in Figure R6 indicates that RT slows with age to a greater extent when spatial, rather than verbal material is employed. We believe that this effect is a result of differences in familiarity of the stimulus material involved, rather than differences in the slowing of search speed of spatial versus verbal working memory. Letters (both heard and seen) are highly familiar and become increasingly more so as subjects grow older.

Hence, the increasing familiarity with age may compensate for any general slowing when the verbal material is employed. The spatial patterns however are equally novel to all age groups and so would allow the age-related speed differences to dominate the latency measures.

Time-sharing. The third cluster of effects are those that failed to indicate any age-related changes. Most prominently these included time-sharing ability. Nowhere in our single-dual task Sternberg task analyses did an interaction occur which might have indicated greater time-sharing decrements for the older subjects, although there was a hint of such a finding with regard to the DDR task. The dual task data of both the Sternberg and the tracking task showed the respective "J shape" and linear profiles that perfectly mirrored their single-task counterparts. It is true that 4 of the 5 dichotic listening measures, related to attention focussing and switching showed an age-related decline. Yet none of these measures appeared to be related to time-sharing performance in the present study. If there were age-related attentional deficits in dichotic performance, these effects did not hinder the dual task performance in the task combinations investigated here.

The factor analysis supported the constancy of time-sharing only in an indirect manner, since there was no factor identified from the Dwyer extention that loaded the dual task performance measures differently from the single task measures. Hence, there was little suggestion that time-sharing ability was an important component of individual differences in the present data.

It is important to realize here that our evaluation of time sharing turned out to be somewhat more restricted than we had intended. While we had initially planned the battery to assess time-sharing between tasks demanding both common and separate resources, it is not clear that we were highly successful in creating the former condition of resource competition. Specifically, the spatial Sternberg task was intended to load resources similar to tracking, but the pattern of dual task interference effects was ambivalent in this regard. Although tracking showed greater decrement with the visual- spatial than the visual-verbal task, the Sternberg task latency itself showed precisely the opposite effect. The net of these two trends suggests that there may not have been major differences in resource competition between the verbal and spatial Sternberg-tracking pairs. Hence, we have not really examined a condition in which two tasks compete for common central processing resources.

Further questions regarding the spatial Sternberg task are raised by the pattern of single task correlations in which the spatial and verbal latencies were found to correlate nearly as highly with each other as the two versions of the spatial and verbal tasks with themselves. Given that spatial and verbal ability are not highly correlated in the population at large, we would not have anticipated this effect if the spatial version truly did tap a different ability.

In addition to time-sharing performance, three further task measures, DDR latency, figure rotation latency, and AS2 latency, failed to indicate any age-related changes. To some extent, these measures may also be clustered together. The DDR task imposes in part a time-sharing requirement (Wickens, 1984). The subject must continuously perceive, store, and respond to overlapping stimuli at various stages of processing in a running "buffer." Hence, like the dual task situations this time-sharing aspect of the task which probably constitutes its most important component may not decline.

Correspondingly, the AS2 and the rotated figures task both load most highly on factor 4 in the factor analyses, sharing that attribute in common, and both showed constancy with age. It is not entirely clear, however, why the tasks loading on this particular factor dissociated as markedly as they did, from second order tracking and maze tracing, whose performance decreased across all age groups. One logical distinction between these two subgroups is that the former tasks are clearly and exclusively visual-spatial, while the latter two involve more non-visual imaginal properties.

Adequacy of the battery. The quality of the battery that we have selected in this initial development phase may be judged on a number of characteristics. First, it is apparent that test-retest reliability on some of the components--particularly those involving the Sternberg task is not overwhelmingly large. It is likely that a trial or two more of practice may be required. Second, it appears that the battery as currently constructed presents an imbalance in favor of one kind of time-sharing task: Tracking with discrete RT. The factor analysis suggests that all variations of the Sternberg task load on essentially the same factor, and do so under both single and dual task conditions. Some of these versions can be eliminated and probably should be replaced by time-sharing requirements of two other sorts: (1) Tracking with a truly spatial task (of which the VS Sternberg task was questionable but the AS task was not), possibly a second tracking task, the AS Sternberg task or the maze task; (2) two verbal tasks: Probably a VV4 Sternberg task performed in conjunction with a working memory task. The following reduced set of Sternberg tasks would appear to be adequate:

	AS2	VS2	VS4	AV2	AV4	VV4
Dual task:	AS2	VS2		AV2		VV4 (with memory)

(AS2, VS2, AV2 — with TR)

This slightly reduced set would allow for a few additional trials of practice to be added in cases where reliability was low.

Despite its shortcomings, the battery however proved more than adequate in discriminating between age-dependent and age-independent factors, and this of course was one major goal of the project. The finding of a general slowing (factor 1) is not terribly suprising (Salthouse & Sonberg, 1982), and the magnitude of this slowing is probably not great enough to be of operational significance. However, both the additional positive finding of the deterioration in some components of spatial ability between the two youngest decades, and the absence of time-sharing changes are of considerable potential operational significances to Naval aviation. It is important therefore that we follow up the present findings with a more detailed examination of both the nature of age changes in spatial skills, and the components of time-sharing skills. What needs to be emphasized as well, however, is that as Figure R9 suggests the variance within age groups is generally far greater than the variance due to age. Many older subjects perform considerably better than the mean performance of the youngest groups. This fact, of course, reitterates the fundamental importance of the concept of functional as opposed to chronological age. Only if age variance predicted performance perfectly would the functional age concept be superfluous.

Finally, of course, it is imparative that the battery be provided some degree of construct validity by correlating its components with actual flight performance. As we indicated at the outset, this will allow us to determine the overlapping variance between age, battery performance and flight ability. Data collection in this phase of the experiment has been completed, and this will be the topic of our next report to be issued within the month.

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Appendix: Day 1 - Day 2 Practice Data

		D1	D2	F	p
Second Order Tracking	RMSE	.435	.361	14.3	.01
CCIT	λ	2.81	2.64	4.2	.04
DDR	% correct	59	61	<1	
DDR	RT (msec)	792	694	384	.05
Sternberg (Single Task)					
VV2	% correct	96	97	<1	
VV2	RT (msec)	642	625	<1	
VV4	% correct	97	96	<1	
VV4	RT (msec)	683	670	<1	
AV2	% correct	96	96	<1	
AV2	RT (msec)	790	801	<1	
AV4	% correct	94	94	<1	
AV4	RT (msec)	890	905	<1	
VS2	% correct	92	93	<1	
VS2	RT (msec)	1002	1001	<1	
VS4	% correct	85	85	<1	
VS4	RT (msec)	1250	1230	<1	
AS2	% correct	77	80	1.20	>.10
AS2	RT (msec)	1295	1278	<1	
Spatial Tasks					
Figure Rotation	% correct	84	87	3.15	.07
Figure Rotation	RT (sec)	1.664	1.54	2.78	.09
Hidden Figures	% correct	90	90	<1	
	RT (sec)	1.47	1.39	<1	
Maze Tracing	% correct	84	85	<1	
	RT (sec)	7.30	6.36	5.86	.02
Dual Tasks					
VV2	% correct	94	95	2.9	.09
	RT	737	704	3.15	.07
	TR	.489	.441	4.4	.04
VV4	% correct	93	94	<1	
	RT	792	768	1.5	>.10
	TR	.478	.450	1.4	>.10
AV2	% correct	93	93	<1	
	RT	837	846	<1	
	TR	.474	.454	<1	

Appendix (cont.)

		D1	D2	F	p
AV4	% correct	93	92	<1	
	RT	924	942	<1	
	TR	.468	.461	<1	
VS2	% correct	90	92	2.09	>.10
	RT	1.070		1.8	>.10
	TR	.498	.483	<1	
VS4	% correct	81	84	2.03	>.10
	RT	1.21	1.21	<1	
	TR	.508	.511	<1	
DDR	% correct	52	53	<1	
	RT	902	800	5.04	.02
	TR	.689	.694	<1	
<u>Dichotic Listening</u>					
% omission				<1	
% intrusion		4.0	3.2	3.61	.06
% incomplete		2.7	1.38	2.9	.09
% mixed		15.6	6.9	20.3	.01
% incorrect ear		2.7	1.1	2.7	.10

END

1-87

DTIC