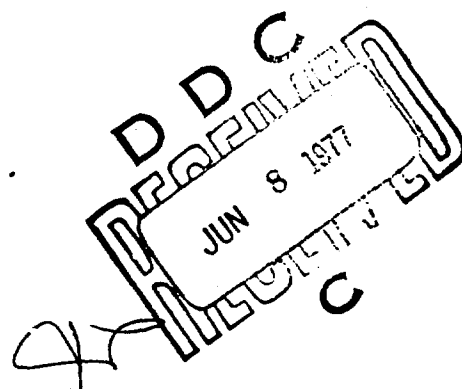


FAA-AM-77-6

10
NW

**PSYCHOPHYSIOLOGICAL EFFECTS OF AGING:
DEVELOPING A FUNCTIONAL AGE INDEX FOR PILOTS:
I. A SURVEY OF THE PERTINENT LITERATURE**

Siegfried J. Gerathewohl, Ph.D.
FAA Office of Aviation Medicine
800 Independence Avenue, S.W.
Washington, D.C. 20591



April 1977

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22151

Prepared for
**U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
Office of Aviation Medicine
Washington, D.C. 20591**

AD A 040322

**AD No. ~~1~~
DDC FILE COPY**

Technical Report Documentation Page

1. Report No. 14 FAA-AM-77-6 ✓	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle 6 PSYCHOPHYSIOLOGICAL EFFECTS OF AGING: DEVELOPING A FUNCTIONAL AGE INDEX FOR PILOTS: I. A SURVEY OF THE PERTINENT LITERATURE,	5. Report Date	6. Performing Organization Code
7. Author(s) 10 Siegfried J. Gerathewohl, Ph.D.	8. Performing Organization Report No.	10. Work Unit No. (TRAIS)
9. Performing Organization Name and Address Office of Aviation Medicine ✓ Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591	11. Contract or Grant No.	13. Type of Report and Period Covered OAM Report
12. Sponsoring Agency Name and Address Office of Aviation Medicine Federal Aviation Administration 800 Independence Avenue, S.W. Washington, D.C. 20591	14. Sponsoring Agency Code	
15. Supplementary Notes 11 Apr 77 12 27p.		
16. Abstract → This report gives a survey about selected material concerning age and aviation-related psychophysiological functions. The author analyzes the results obtained by many investigators from longitudinal and cross-sectional studies that may be useful for the development of a functional age index for pilots. Particular emphasis is given to studies on the effect of age differences as measured by standardized tests of sensory, perceptual, mental, cognitive and neurophysiological functions and processes, and the quantitative or objective assessment of personality traits and structure. A few examples of graphs, tables, curves, and mathematically expressed relationships between these parameters and age are given. The age-related changes of these variables and their implications to possible and actual pilot performance are discussed. A		
17. Key Words Pilot Aging Functional Age Index Psychophysiological Age Effects	18. Distribution Statement Document is available to the public through the National Technical Information Service, Springfield, Virginia 22151	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 22. Price \$3.00 PC .95 MF

264320 C

NTIS	Mobile Section	☒
DOC	Butt Section	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY	DISTRIBUTION, AVAILABILITY CODES	
	Dist. Avail. and/or SPECIAL	
	A	

PSYCHOPHYSIOLOGICAL EFFECTS OF AGING: DEVELOPING A FUNCTIONAL AGE INDEX FOR PILOTS: I. A SURVEY OF THE PERTINENT LITERATURE

I. Introduction.

Human aging is a biological phenomenon with profound implications not only for the individual but for society and the general public as well. Its consequences range from altered structures and functions of the component tissues of the body to an altered relationship of the organism to its physical and social environment.

In a series of articles dealing with the results of the Normative Aging Study conducted by the Veterans Administration's out-patient facility in Boston, Massachusetts, the contributors stated their belief 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 areas or aspects of aging.⁵ This ambiguity of age as a reliable indicator of gerontological changes has led to the derivation of the concept of functional age, which accommodates the fact that persons age at different rates along different dimensions.⁶⁸ The strategy of functional age research is therefore aimed at collecting data on age-related biological, physiological, psychological, and neurological processes and functions and at correlating such data with chronological age. Functional age is thus thought to be a composite of many age-related measures which can be approached through statistical analysis.²⁷

The ultimate goal for the establishment of functional age as a proficiency measure is to predict the biological or, in our case, psychophysiological changes based on actual measurements obtained from individuals or groups of individuals at various points of their life span. If the various functional age points of a person were periodically determined, such changes could be detected and interpreted as to their operational implications.

In order to arrive at an appropriate approach to such an effort, it is necessary to collect data on age-related functions and to analyze them in regard to their general and operational validity. This approach seems promising. It may also be possible to monitor the aging process in one way or another or to accept deviations from an established norm in one or several dimensions as a criterion of loss of vitality, proficiency, or of incapacitation. Functional age could then become a useful and convenient concept which could be applied to problems of variable retirement, for example.

The purpose of this paper is twofold. First, it surveys the material presently available on age and aviation-related psychophysiological functions. Secondly, this summary of results obtained from longitudinal and cross-sectional studies concentrates on research data, that have yielded quantitative information which can be displayed in graphs, curves, and mathematical models. A few examples of these are given to illustrate the point. They show material obtained by many investigators on the biological, physiological, psychological, and neurological functions and processes. There is reason to assume that these measurements can be combined in certain cases to be representative of the aging process within a certain target population. In our case, the target population consists of pilots. Hence, those measurements and statistics are presented here which are associated with or thought to contribute to the behavior, performance, and proficiency of aircraft pilots. These data are grouped as follows: (1) sensory functions, (2) perceptual functions and processes, (3) mental and cognitive processes, (4) neurophysiological functions, and (5) personality traits and structure. The age-related changes of these variables or parameters and the theoretical and experimental strategies for their investigation and use will be discussed.

The assistance of E. Jean Grimm in preparing this manuscript for publication is gratefully acknowledged.

II. Sensory Functions.

A. *Vision.* It has long been known that sensory functions deteriorate with increasing age. In visual perception, almost all of the functions and properties of the eye are affected. One of the best-known examples is loss of accommodation or senescent hyperopia (presbyopia); i.e., the ability of the eye to focus on objects at varying distances. Precise accommodation curves were obtained by many investigators.^{21, 24} They show the very early decline of accommodation and the steepest slope during the 40- to 50-year period. Similar decreases, but not as early and drastic, are found in visual acuity and the minimum light threshold of the dark-adapted eye, which occur particularly during the 60th decade, and in the mean pupil diameter.³⁶ The latter one is involved in the process of accommodation. The rate of adaptation (i.e., the change in the sensitivity threshold as a function of time in the dark) is, like pupillary size, contraction latency period, binocular fusion time, and color vision, only mildly affected by aging. Responses to flicker and flicker-fusion frequency also vary

with age and show a sharp decline in older people and so does the extent or size of the visual field.⁶² While up to age 45 depth perception (stereopsis) changes very little, it declines at a much faster rate thereafter.⁷ There are some indications that the mechanical effects of aging in the anterior segment of the eye occur earlier than those affected by metabolic changes in the retina. Both static and dynamic visual acuity decrease after age 54, probably due to changes in efficiency of the visual apparatus or its functions.³⁵

An example of the effects of age on vision showing the decrease in the amplitude of accommodation is given in Figure 1.

B. *Hearing.* Very accurate hearing curves have been plotted over the years.^{8, 82} There is an age-related diminishing of the general auditory sensitivity (total and relative) and a hearing loss especially for the higher frequencies (above 2,000 Hz), but the very low frequencies (below 100) are also affected. It appears that most individuals above age 40 show some loss of high tone perception. Recent research in this area

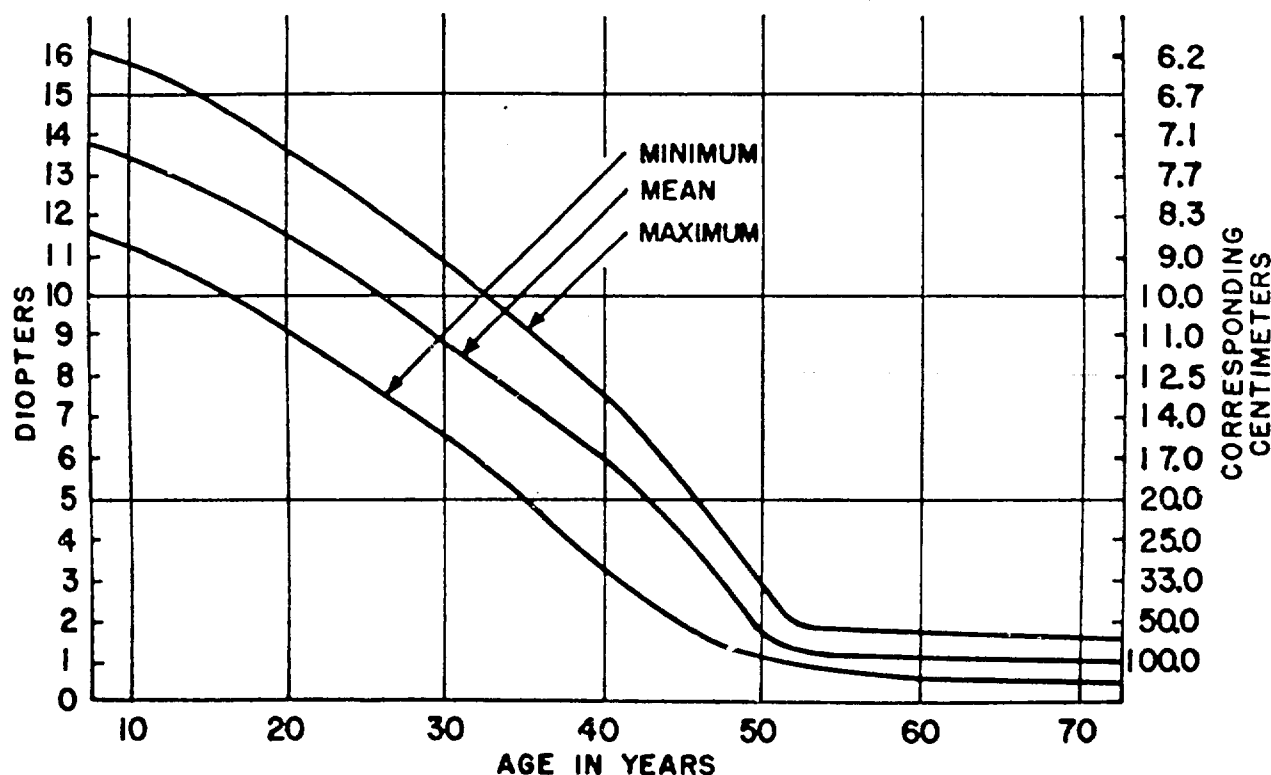


FIGURE 1.—Age changes in the amplitude of visual accommodation based on Duane's curves of norms and accommodation. (Curve based on Figure 26 in Crouch, E. L.: The Relation Between Illumination and Vision, ILLUMINATION ENGINEERING, 40:747-784, 1945.)

concerns the associated processing abilities, since the aging auditory system has decreased capacities in integrating and understanding distorted messages even in persons who have relatively normal audiometry. In a delayed speech feedback experiment, it was found that the younger subjects were less affected by the delay than the older ones, but the differences were minor.¹¹ Similar results were obtained in a two-click discrimination task. The performance of persons of different age groups on a dichotic listening task showed that recall declined with increasing age. The deficit was predominant for the left-ear material.²⁰ In an attempt to develop an auditory functional age formula, 16 different auditory variables were used in a multiple regression analysis.⁶ The 10 highest ranking correlations ranged from .40 to .25, the two highest being air conduction at 8,000 Hz and speech reception threshold. All correlations obtained in this experiment clearly confirm the well-known hearing decrement observed in the various age groups. An experiment on the effect of age on the perception of vibration showed that the threshold of vibration sensation rose with age.³⁷ The logarithms of the threshold values were directly proportional to age, and the standard deviations increased proportionally. There also is a correlation between chronological age and voice characteristics. A "classical" hearing acuity curve as affected by age is shown in Figure 2.

III. Perceptual Processes.

A. Data Acquisition. Age-related changes in perception are not necessarily caused by, or even related to, changes in the sensory functions. While sensory stimuli may include elements of stimulus integration, interpretation, and judgment, which contribute to the detectability, processing, and application of the sensory input, the stimulus or data handling process is very complex and can proceed independently of the original input. An example of this process is the visual illusion, which is characterized by the false interpretation of a real sensory image or impression. A different but related factor in perception is time; e.g., information processing time, response time, and the timing of sensory input. Older persons need longer exposure time for form identification. In experiments using

the Mackworth clock test, for instance, older subjects were found to be as "vigilant" as the younger ones, but their performance declined significantly after 45 minutes. This deficit in visual performance of the elderly was particularly obvious when stimuli of short duration (1 sec or less) were applied.³⁹

During a "paced inspection task," sequences of letters and digits were presented to subjects who had to monitor the occurrence of consecutive letters or digits. The age-related impairment of performance was most pronounced after age 60.²⁶ It was suggested that this type of performance can be improved if the information is simultaneously presented visually and auditorily instead of only visually. Such kind of presentation helped the older people more, because the age-related reduction in information processing capacity is compensated by relegating the auditory sequence to a kind of secondary task. By splitting the total sequential process into two parts, performance in the primary visual channel can be maintained at a higher level.

In view of the fact that perceptions are usually transformed into cognition and action and that they are also closely related to neurological, psychomotor, and central mechanisms, complex perceptual processes have been likened to such concepts as information and communication theory. Timing appears to be an important factor involved in these mechanisms, although experience and strategy may play a certain role in communicating and information processing. Since the observed age difference between young and old persons are neither consistent nor very large, it is hypothesized that specialized training and extended practice, both typical for older people, may help to keep their performance deficit at a minimum.

B. Information Processing and Channel Capacity. Information theory deals with the amount of uncertainty involved in any communication process. It is based on the assumption that the human brain is a rather noisy communication channel and that signal detection proceeds statistically in that the cognitive mechanisms always test hypotheses, so to speak, in order to discriminate between noise and signal. It is clear that the time available for signal sampling and processing is very important for

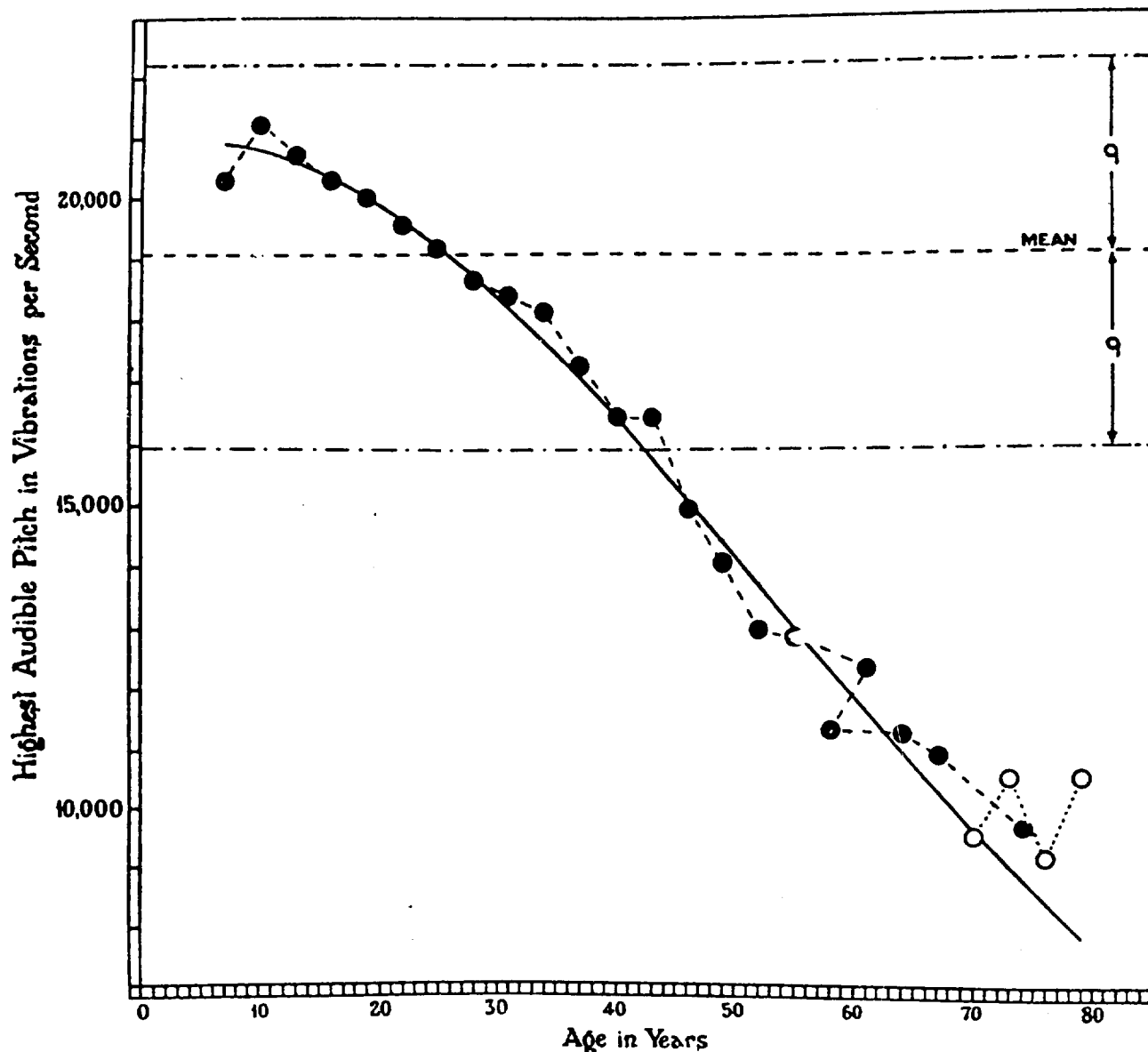


FIGURE 2.—Age changes in the acuity of hearing. Note that: (a) points deduced from small frequencies near the terminals of the range are marked by clear circles, and a heavy circle is shown replacing several such points; (b) the standard deviation σ of the dependent variable is indicated so that the extent of the total variation of one character with the other will be readily apparent. (Reproduced with permission from Diagram I in Koga, Y., and G. M. Morant: On the Degree of Association Between Reaction Times in the Case of Different Senses, *BIOMETRICA*, 15:346-372, 1923.)

the outcome of this type of signal detection. Experiments aimed to throw some light on the timing characteristics of this process furnished some interesting results about the task load. Rapid judgments and decisions had to be made in the interpretation of a large variety of signals. While there was no obvious slowing of the subject's response time to the stimuli, subjects over 40 years of age were relatively more susceptible to information overload than the younger ones, particularly when the task involved the presence of temporally contiguous (or masking) signals.¹⁰⁰

Recently, investigations of the effects of backward monoptic and dichoptic visual noise masking also showed that older subjects were more affected by visual distortions than younger subjects.^{20, 57} The authors conclude that this effect seems to be, at least partly, attributable to age changes in the central perceptual mechanisms involved in the processing of signals. Backward masking studies of various kinds seem to hold considerable promise for the assessment of the peripheral and central components of age changes in visual processing.

C. *Reaction Time.* Simple reaction time (RT) (i.e., making a response to one discrete stimulus) becomes definitely slower with increasing age. Reaction time curves and mathematical expressions of this function have been known for more than 50 years.⁵⁸ Relative to other functions, reaction time appears to mature early, reaching its minimum at about age 20. It seems that even in this simple stimulus-response mechanism, central processes play an important part. Choice reaction times are always longer than simple RT at all ages. When choices between several possible responses are required, an extra time delay has been measured with older subjects.²² In experiments including complex reaction tasks, the older test subjects were significantly slower in complicated test situations than the younger ones, particularly when the tests involved reversing or changing the previously learned stimulus/response relationship of the signals.⁹¹ There were no significant differences between the younger (20-28 years) and the older (48-62 years) age groups in motorically responding to the various tasks, but the information processing rates were different: 13.7 and 10.6 bits/sec for younger and older subjects, respectively.⁵⁰ When test subjects had to make one-syllable responses in order to form two-syllable words, the choice RT's were found to be lower in older than in younger subjects. The difference between simple and complex reaction times was greater for the older than for the younger ones.¹¹² There were some speculations that the older subjects were more affected by the length of the alerting period (i.e., the time period before the stimuli were presented), but it was found that the older persons did not benefit from extending the alerting periods or other advance information. Age changes in choice reaction tasks also manifested themselves in increases in errors and increased variability of RT.²³ Long-term verbal habits, as measured by these word-association tests, however, facilitated the performance of the older subjects on some tasks. This shows that they were more inclined to think in realistic terms than the younger subjects who were more oriented toward abstract thinking.⁸⁰

In an experiment involving visual perception, the time needed to discriminate and then react improved from a 15-16 year group, reached its peak at 30-35 years, and then declined steadily from 55-60 years to the oldest group (70 and

over).⁹⁰ There is also evidence that the older individuals responded relatively slower to repetitive stimulus patterns than to changing stimulus patterns. Their longer reaction time reflects impaired efficiency in initiating motor responses rather than in discriminating between the visual stimuli.¹¹⁴

By measuring promptness of response with a word-identification test, it was found that the older subjects gave fewer responses. This was probably due to the slowing of the perceptual processes involved.⁵⁹ It now seems that with increasing age the processing of the perceived information and the monitoring of ongoing responses cease to be integrated by the central nervous system as efficiently as during the younger years and that the two steps may have to be undertaken sequentially rather than simultaneously.⁷⁷ This is in agreement with our earlier statements. In a more recent study involving stimulus repetition in a two-choice experiment, it was found that response latencies increased with age and that the older individuals' longer response times reflect impaired psychomotor rather than decision-making efficiency.^{11,5} Since previous results suggested that motor factors were not adversely affected during such tasks, the ambiguity of the results still exists.⁹⁶ Two examples of reaction time curves as a function of age are given in Figure 3.

D. *Psychomotor Performance.* Sensory, perceptual, decision, and motor processes are involved in psychomotor performance. All are more or less affected by aging. It was found in early experiments that a more complex motor response can in some way enable compensation of an otherwise slow RT. Experiments in which complex sensorimotor coordination was required have shown pronounced deficits with age. In particular, slowing of speed was observed during writing, finger tapping, and tracking.^{67, 117, 118}

An experiment to determine the finger-tapping rate by alternating between two targets showed that the rate improved in accuracy and speed from the 20th to the 30th year and thereafter declined with age.¹⁶ No significant age differences were found within the range of 17-41 years of age on the USAF Rotary Pursuit Test.¹⁸ In another experiment, the test subjects had to respond to either tones given monaurally in each ear or to voice commands presented binaurally

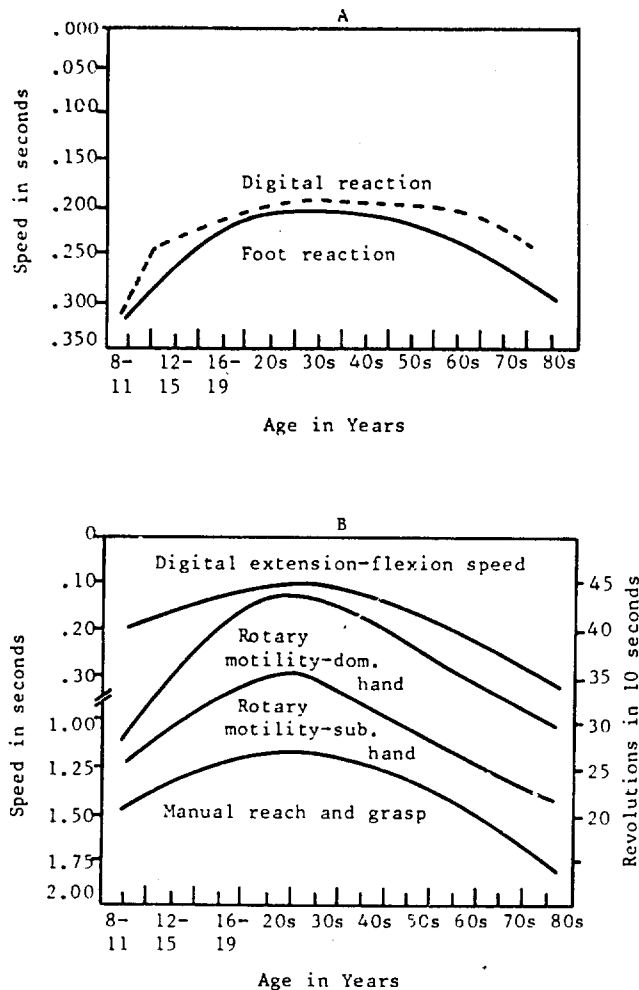


FIGURE 3.—Age changes in the speed of reaction time. Graph A—digital and foot reactions compared. Graph B—four types of hand and finger reactions compared. (Adapted from Figures 4.2 and 4.3 in Dennis, W.: *Age and Behavior—A Survey of the Literature*. USAF School of Aviation Medicine, Randolph Field, Texas, P. No. 21-0202-0005, 1953. Original figures from Miles, W. R.: *Measures of Certain Abilities Throughout the Life Span*, PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES OF THE UNITED STATES OF AMERICA, 17:627-633, 1931.)

in head phones. The younger subjects responded significantly faster than the older ones to both types of stimuli. Moreover, the difference in response time between the directionally presented tone cues and the voice cues were significantly greater for the older people.⁹²

When the effect of task complexity and stimulus duration on perceptual motor performance was studied in two disparate age groups, the older subjects reacted 30 percent slower and moved 76 percent slower than younger ones. Both perception time and movement time were

slower in complex tasks than during a simple performance test. Young subjects moved more rapidly with the 0.110-second stimulus, while older subjects moved relatively faster when a 2.0-second stimulus was presented.¹¹² In general, the perceptual motor performance of the older subjects was found to be substantially worse than that of the younger ones. This difference was due particularly to the longer time required for discrimination of the stimulus and the decision-making process.⁶¹ The older subjects also responded more slowly when advanced information signals were presented. These data suggest that older people are at a considerable disadvantage when coping with new test situations and acquiring new skills, since they must learn to predict further ahead in time than their juniors in order to be efficient. The better performance of the elderly in certain laboratory tests was due more to their increased eagerness to perform well than to their perceptual motor capabilities. This may not be of help, however, in practical situations where the ability to anticipate is essential. Functionally, the inferior performance of the elderly is interpreted as reflecting a slowing of the general speed factor, which underlines most perceptual and neural processes.^{13, 76}

It is commonly found in a wide variety of performances that individual differences increase with age.^{111, 112} Whereas motor coordination seems less affected by the aging process, performance decrement is most apparent in functions which require visual motor responses or when speed is of particular importance. A certain amount of the decrement in psychomotor performances includes the mental or thinking part of the processes involved. This can be found even in experimental results which show a wide range of individual differences.⁸⁷

The effects of age on the 12 ability tests of the General Aptitude Test Battery (GATB) were examined as part of the Normative Aging Study. All scores showed highly significant declines with age, but the magnitudes of the decrements differed greatly.⁶⁹ Most affected by age was the psychomotor test requiring the disassembling of a simple mechanical gadget. Performance on the three ability tasks, namely Disassemble, Tool Matching, and Turn, which required the manipulation of small objects, accounted for about 25 percent of the variability in chronological age.⁴⁰

There is also some evidence that there is more than one speed factor involved in psychomotor performance and that the speeds of perceptual, motor, and complex cognitive functioning are relatively independent of one another. In a complex experiment performed to throw some light on the interaction of these functions, it was found that the older individuals performed more poorly than on certain tests requiring speed. Again, information processing was most affected and declined with age.¹¹⁶ Experiments confirmed a similar decline of vigilance as part of a psychomotor assessment. Older test subjects' performance decreased more at the fastest speed used than did that of the younger ones.¹¹¹ In another study measuring the response speed deficits and intellectual performance in the elderly, it was suggested that a major proportion of intellectual decline in old age reflects performance rather than competence deficits.⁵² It was also hypothesized that older subjects make best use of their capacities through unconscious (or conscious) improvement of their performance (i.e., they tend to adopt the optimum strategy to solve a problem more readily than do the younger ones). However, an experiment on risk taking showed that the older subjects' performance did not improve through unconscious optimization when compared to that of the younger group.⁸¹

IV. Mental Processes.

A. Learning. The ability to retain new information in a readily accessible state deteriorates with increasing age. This decline has been attributed to an impairment of the mechanisms active either in the acquisition or the storage of new information, and there is evidence to support both theories. It seems quite probable that efficiency declines in all steps involved, namely acquisition, storage, recognition, and recall. A series of experiments in paired-associate learning has demonstrated that the capacity to acquire new verbal information deteriorates with age faster than the other processes involved.¹⁰⁵ Comparisons between very old persons and those in the prime of their lives showed, of course, the former at a disadvantage in tests of virtually any cognitive function. This encompasses such specialized processes as discrimination learning consisting of reversal, intradimensional, and extradimensional tasks. It was found in an experiment on discrimination learning and transfer

of training that the younger subjects made significantly fewer errors than did the older trainees.⁶⁵ This seems to indicate a greater susceptibility to negative situational transfer or mediational deficient functioning with increasing age.

Performance scores and learning curves obtained with the U.S. Air Force Discrimination-Reaction Time Apparatus declined steadily after about 25 years of age. As expected from the literature, the classical nonmonotonic age learning function was found in these experiments (i.e., that capacity for learning decreases with age).⁶⁶

The reason for the reduced ability of the elderly to properly learn, recall, and process any information may be due either to the diminishing capacity of the aging brain to form structured traces of the incoming message or to an increase in neural noise as previously hypothesized.²³ An attempt to improve the learning ability of the elderly by the administration of a drug, propranolol, as an autonomic nervous system stimulant, yielded promising results.³¹

B. Memory. Short-term memory generally shows a relatively slow decline after maturity and a marked decrease during the sixties and seventies, particularly in tests using unfamiliar material.^{121,122} While there is experimental evidence that retrieval time becomes slower, a comparison with perceptual and response factors indicated that memory searching time is less age related.^{3, 56} In order to find an answer to the storage versus retrieval deficit question, series of experiments were conducted using several span and recognition tests. When simple and complex visual patterns were applied, age-related decrements in short-term memory were determined. They interacted in a very complex manner with other variables, such as stimulus condition (paced or self-paced), complexity, exposure time, etc.

The analysis of the encoding process did not suggest any reliable relationship between short-term memory and encoding strategy or retrieval phase but did show age-related deficits at the recognition stage.² On the other hand, older persons showed no deficit in immediate memory span and retrieval from old storage but highly significant impairment in learning long digital sequences and verbal items. This was interpreted as storage disorders instead of a retrieval deficit.²⁹

It has been suggested that methodological problems may account for some of the differences in results obtained by age-related memory studies.⁶ Possibly, repeated testing and practice could improve the memory in old persons, but experimental proof of this theory was not obtained. Although there were age-related deficits with two types of test material used, the sense modality effects (visual vs. aural) were similar for all age levels.¹⁰⁵ Although no differential output or input interference due to age was found for items assumed to be recalled from long-term memory, an overall deficit was observed on these long-term items.⁹⁴ Hence, susceptibility to interference appears to be closely associated with the relatively poorer performance of the older subjects in both short-term and long-term memory tasks.^{15, 106}

Similar results were recently obtained in experiments on semantic (verbal) memory. The age effects were different for recall and recognition in that the older group responded more slowly on the recognition but not on the recall part of the task. The response times of the older subjects were less affected by the dominance of the to-be-retrieved information than were those of the younger ones. These results were interpreted as suggesting that subjects in the higher age brackets may have retrieved information just as fast as the youngsters but that they require longer times to decide upon the response.³⁴ Both young and old subjects performed more poorly as the stimulus arrangement became more complex, and there is evidence that the decrement was more pronounced with the older group.³¹ Practice or repeated testing may help somewhat under these conditions, but it did not seem to aid the elderly more than the young.¹⁰⁹ Perhaps differences in interest and motivation can influence what will or will not be recalled.⁴¹ An example of the age-related recall function obtained in experiments using nine-digit numbers is shown in Figure 4.

C. Problem Solving and Performance. Several studies reported during the past 15 years deal with the effects of age on intellectual and cognitive functions. Their results—even those obtained by the same experimenters—are sometimes ambiguous.⁴⁹ Using the Wechsler-Bellevue and the Wechsler Adult Intelligence Scale, decline and no-decline of test scores with age were found in different populations.¹²¹ The effect of

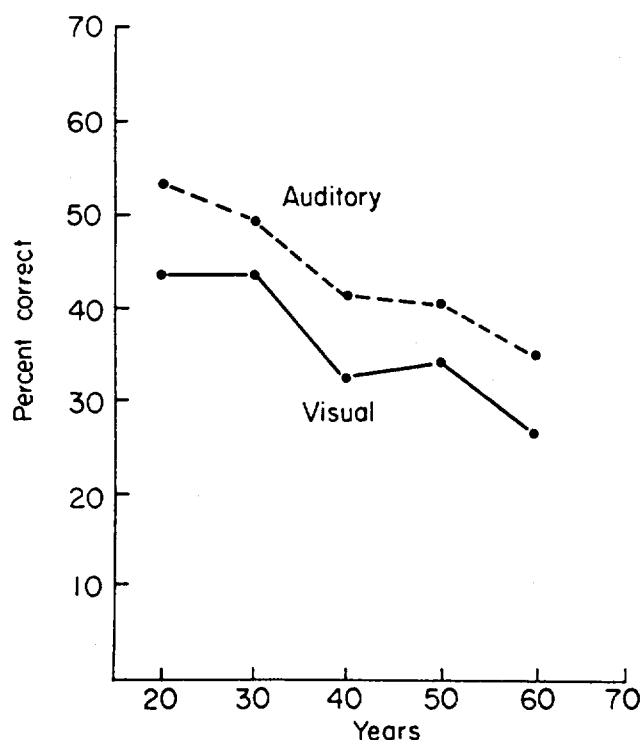


FIGURE 4.—Mean complete recall performance with nine-digit numbers presented aurally and visually to five age groups. (Reproduced with permission from Figure 7 of Talland, G. A.: *Human Aging and Behavior*, New York, Academic Press, 1968, 322 pp.)

aging as measured by the General Aptitude Test Battery (GATB) showed declining scores on all 12 subtests. Most affected was the psychomotor test, while Arithmetic Reasoning and Vocabulary were least affected.⁶⁸ Age-related performance decrement in a paced inspection task was most marked after age 60.³³ However, there seems to be enough evidence to conclude that some intelligence test scores do not decline before age 65. This is especially the case with measures of verbal abilities; in contrast, test and performance scores which depend on sensory and motor processes declined with age (see Figure 5).³⁹ As previously reported, older subjects tended to slow disproportionately in performing speeded tasks in a problem-solving reaction-type test. The older subjects also made more errors, and the correlation between slowness and inaccuracy increased with age. Elderly persons are not necessarily more careful; or, if so, this cautiousness does not effectively compensate for error proneness. The age effects in error proneness and the slowing of cognitive functions indicate an increased difficulty of the aged in maintaining effective control of cognitive activity.¹⁴

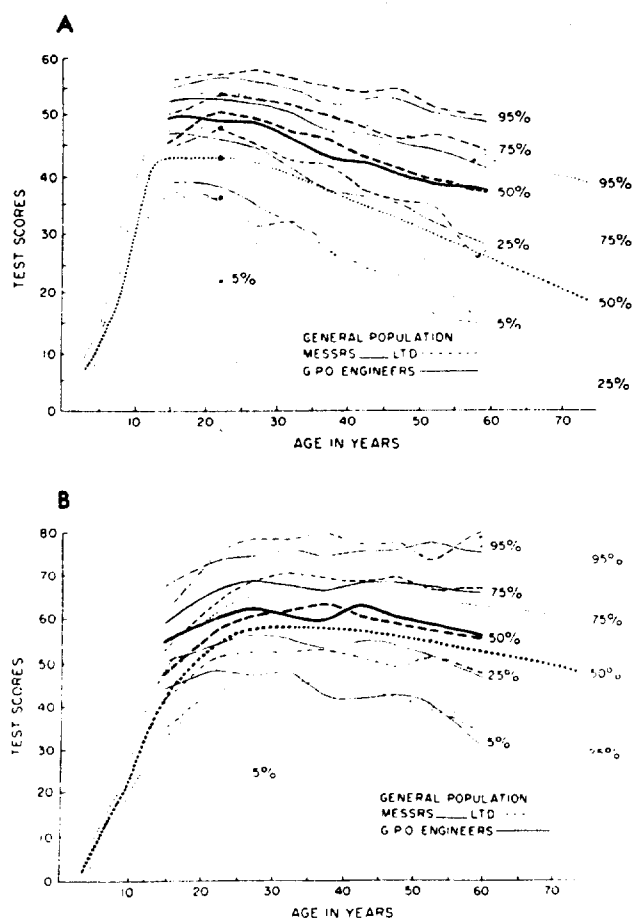


FIGURE 5.—Performance as a function of age and occupational status. Graph A—performance on Progressive Matrices, a nonverbal intelligence test. Graph B—performance on the Mill Hill Vocabulary Test. (Reproduced with permission from Figures 8-3A and 8-3B in Birren, J. E.: *The Psychology of Aging*. Englewood Cliff, New Jersey, Prentice-Hall, Inc., 1964, 300 pp. Adapted from Graphs I and II in Foulds, G. A., and J. C. Raven: Normal Changes in the Mental Abilities of Adults as Age Advances, *JOURNAL OF MENTAL SCIENCE*, 94:123-142, 1948.)

A great deal of research into the changes which occur in skilled performance with advancing age suggests that the processes most crucially affected are those central ones which mediate the translation of perception into action. This can be interpreted as a deterioration of the operator's capacity to transmit information from display to control.⁵⁰ If events requiring fast action by an operator occur at random, they impose a continuous risk of momentary "overloading" of channel capacity. Another disadvantage for older people who operate mechanized equipment is that the direct relationship between what is seen and what is done is lost. It has been shown

that indirect display-control relationships are disproportionately more difficult to handle for older people than for younger ones.

In an analysis of intellectual performance of older persons, tests measuring verbal achievement reflected little or no decline.^{32, 34} By using a superior synonym test and a sophisticated qualitative scoring technique, however, age differences were found with the fine nuances of word definitions: The performance of the 70-year group was far below that of the 20- to 60-year group.¹² As to the testing of nonverbal intelligence, it was found that there were little differences in performance among young, middle-aged, and old individuals. It was suggested that intelligent old subjects may retain an ability to learn to a certain degree from immediate experience which enables them to compete successfully with younger ones.^{120, 121}

Extensive studies were recently conducted by several investigators to measure age-related differences in mental abilities and skills using a variety of psychological test batteries.^{38, 42, 73} Performance on practically all of these tests showed decreasing efficiency with age, but the degree of decline of test scores varied remarkably. Several of the mental functions, such as arithmetic reasoning, vocabulary, and verbal skill, did not decline as much as other functions. The major age-related differences of these functions were observed between subjects in their sixties or seventies and the younger ones. The largest decrements were measured in tasks which were unfamiliar to the subjects.⁴³ A review of the literature on age-related Piagetian cognitive functions (logical operations, animism, moral development, egocentrism) indicated wide individual differences in adulthood cognitive performance, showing continued cognitive development for at least some middle-aged subjects on certain tests. Generally, lower levels of cognitive functioning were noted for elderly subjects as compared to the adult groups.⁵⁴

Data obtained by a study of age differences in intelligence performance support the hypothesis that part of the often-reported age effects in components of intelligence is not indicative of a loss in task-specific abilities but may reflect, at least partly, the effect of nonintellective factors associated with such variables as pretest experience and subtest position.⁴⁶ Indications of

cohort-related differences were also found in age-related intelligence studies.⁵⁶ Figure 6 shows cohort differences on some primary mental abilities and on measures from the test of individual rigidity.

The results of a 35-year followup study of intellectual functioning showed a slight insignificant rise in vocabulary level but a decrease in all groups of mental efficiency scores and indexes for the 60- to 74-year-old subjects.⁴⁷ When the scores of each older individual were compared

with his scores obtained 35 years earlier, all differences from the higher indexes were significant at the 0.01 level or beyond. However, variation in the amount of decline is pronounced among older persons and many, even though they may have lost their former efficiency, were still on par in some areas with the average young person. Table 1A shows the mean scores, standard deviations, differences, and significance of the differences of the scores obtained in the 1930's and 1970's. Table 1B shows the mean total efficiency

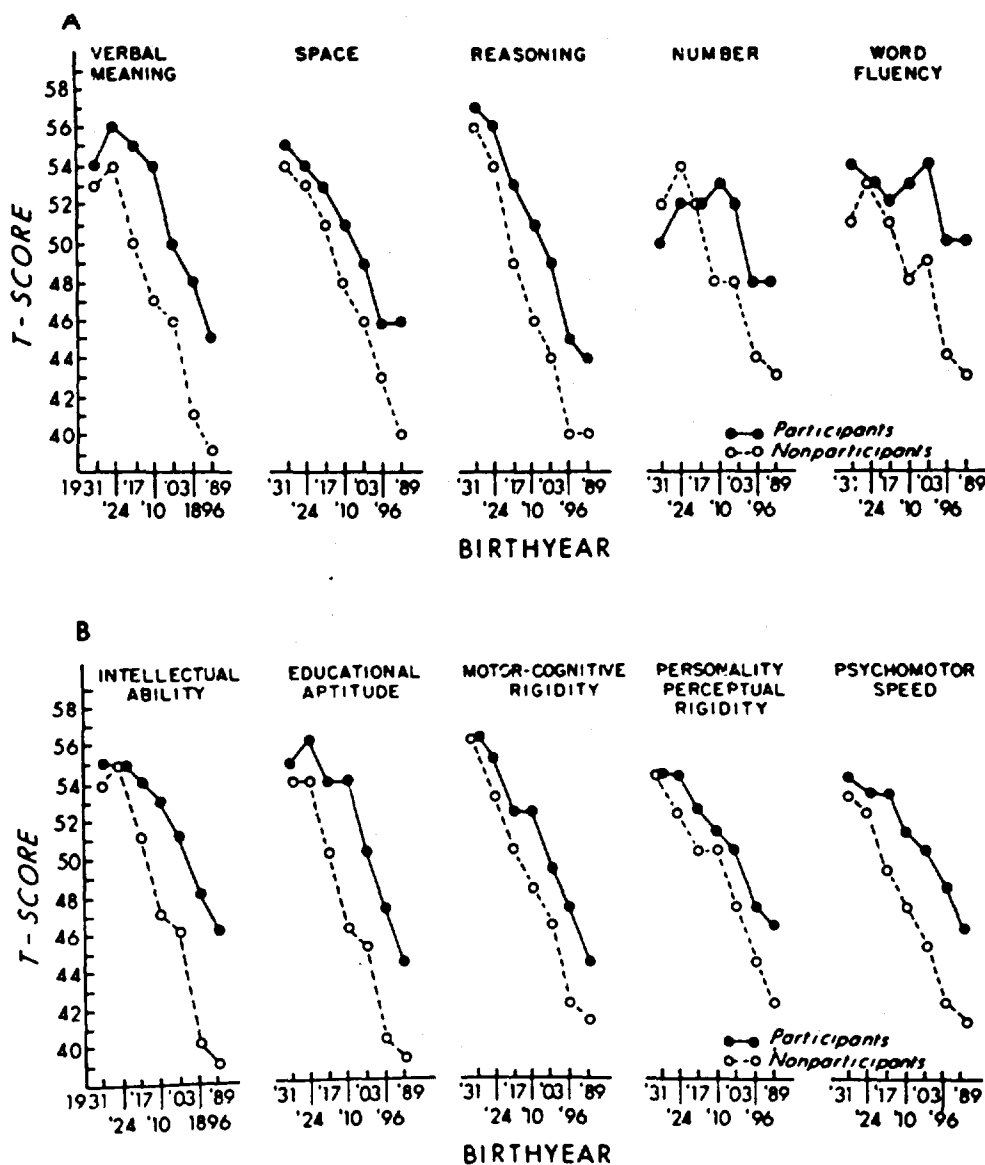


FIGURE 6.—Cohort-related differences on the primary mental abilities (Graph A) and on both global indices of mental ability and measures of behavioral rigidity (Graph B). (Reproduced with permission from Figures 1 and 2 in Schaie, K. W., G. V. Labouvie, and T. J. Barrett: Selective Attrition Effects in a Fourteen-Year Study of Adult Intelligence, *JOURNAL OF GERONTOLOGY*, 28:328-334, 1973.)

TABLE 1. Data on Intellectual Functioning From a 35-Year Followup Study by Gilbert⁴⁷

A. Average Early and Late Efficiency Scores on the Groups of Tests								
No.	Vocabulary	Total Score	Easy-Old Material	Repetitions	Initial Learning	Retention	Motor Reactions	Easy Continuous
1930's	14							
Mean	18.71	18.19	18.24	16.97	17.21	18.84	20.05	17.68
SD	1.87	1.12	1.44	2.40	1.64	2.58	1.77	1.48
1970's	14							
Mean	19.71	15.15	17.39	15.95	13.18	13.22	16.10	14.78
SD	.80	2.07	1.68	2.17	3.69	3.72	3.11	2.04
Diff.	+1.00	-3.04	-0.85	-1.02	-4.03	-5.62	-3.95	-2.90
SE _D	.56	.65	.61	.90	1.12	1.26	.99	.70
t	1.77	4.12**	1.38	1.14	3.60**	4.48**	3.98**	4.08**

B. Efficiency Indices of the Two Groups								
No.	Mean Total E.I.	Easy-Old Material	Repetitions	Initial Learning	Retention	Motor Reactions	Easy Continuous	
1930's	14	+1.00	+1.06	-0.20	+0.16	+1.34	+2.39	+0.29
1970's	14	-2.82	-0.21	-1.94	-4.50	-4.95	-2.17	-3.49
M _D		-3.82	-1.29	-1.74	-4.66	-6.29	-4.56	-3.78
SD _D		1.71	1.79	1.82	3.69	2.55	2.27	2.01
SE _{M_D}		0.45	0.47	0.48	0.98	0.68	0.61	0.54
t		8.48***	2.74*	3.62**	4.75***	9.25***	7.48***	7.00***

C. Efficiency Indices Based on Early Vocabulary Levels								
No.	Mean Total E.I.	Easy-Old Material	Repetitions	Initial Learning	Retention	Motor Reactions	Easy Continuous	
1930's	8	.01	+1.15	-0.69	+0.85	+1.47	+2.35	+0.94
1970's	8	-1.46	+0.50	-0.84	-2.71	-3.01	-1.35	-1.94
M _D		3.07	0.65	0.15	3.56	4.48	3.70	2.88
SD _D		0.35	0.97	1.45	2.59	1.86	2.58	1.60
SE _{M_D}		0.30	0.34	0.51	0.92	0.65	0.91	0.56
t		10.23***	1.88	0.29	3.87**	6.89**	4.06***	5.14***

* $p < .02$ ** $p < .01$ *** $p < .001$

indices of the two groups, their efficiency indices on the six separate groups of tests, the differences between the early and late indices, and the significance of these differences. Finally, Table 1C shows the average efficiency indices of eight test subjects based on the vocabulary scores they obtained during their first test in the 1930's. Generally, it was noted that adult persons perform quite well on such tests, whereas many old persons show an apparent regression in task mastery, performing at levels similar to those of young children.¹⁰

In summary, it appears that older people usually perform more poorly on tasks requiring sensorimotor, mental, and cognitive performance, and problem solving (see Figure 7). These deficits are due not only to the slowing process of the functions involved but also to such factors as lack of practice, loss of touch with current problems, and unawareness of present needs and

requirements. The deficit is compounded slowly from the midfifties on, followed by relatively pronounced declines in cognitive performance in the sixties and seventies and thereafter. The interaction of these variables complicates the interpretation of the deficit as well as its implication to practical situations. It also appears that maturity and experience can hardly compensate for the deficit in some of the functions which are critical for sustained performance and proficiency.

V. Neurophysiological Functions.

A. *Biological Considerations.* Experiments have shown that cells, particularly the highly differentiated ones in many critical organs such as the human brain, die in the course of aging.¹ This seems to be indicative of the physiogenetic basis for the age changes in the various body systems and functions, which affect the daily be-

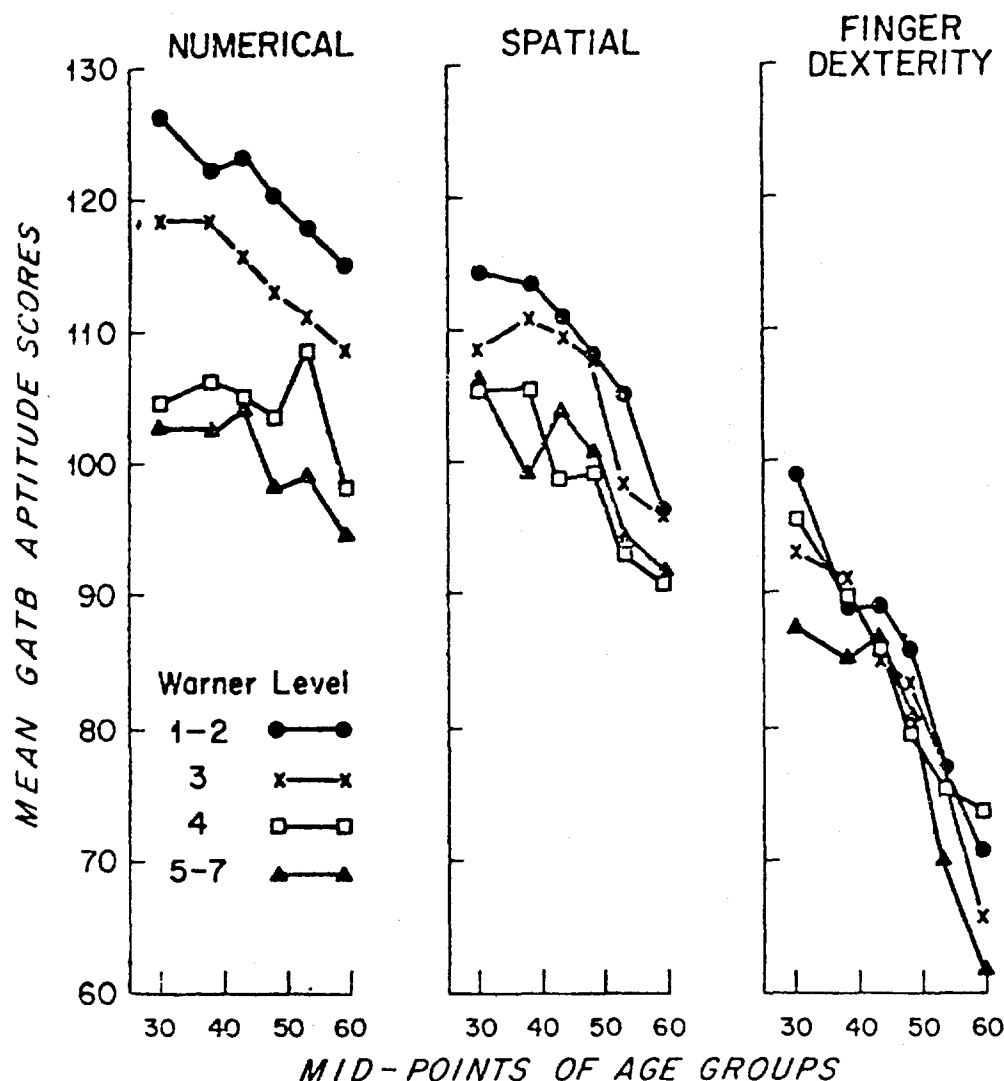


FIGURE 7.—Effects of age on three GATB aptitudes. The Warner Level indicates the socio-economic status of the test subjects. (Reproduced with permission from Figure 1 in Fozard, J. L., and G. D. Carr, Jr.: Age Differences and Psychological Estimates of Abilities and Skills, *INDUSTRIAL GERONTOLOGY*, 13:75-96, 1972.)

havior pattern of the individual. Many observations on both healthy and sick or diseased persons have indicated that there is a decrease in cerebral metabolic rates or oxygen consumption with age.⁶¹ Although there was no significant age effect related to blood flow in the brain, there was a considerable and statistically significant decrease in cerebral glucose utilization in otherwise healthy elderly subjects, resulting in a somewhat reduced mental capacity. In some instances, there was evidence of loss of cerebral tissue.²⁵

The decrease in skeletal-muscle mass with increasing age explains to a large extent the decrement of physical and muscular efficiency (see

Figure 8). The cardiovascular reflexes, which adapt the blood circulation to muscular and heavy aerobic work, also seem to be affected. There is indication that decreased sex hormone production and reduction of thyroid hormone may be involved in the physical deterioration of older persons.²³ While one cannot imply that the decrement in the total number of cells and the deficiency of oxygen metabolism within the cells are the only factors in aging, both variables are most intimately related to the age factor. Multiple causality is undoubtedly involved in such a complex process as aging.

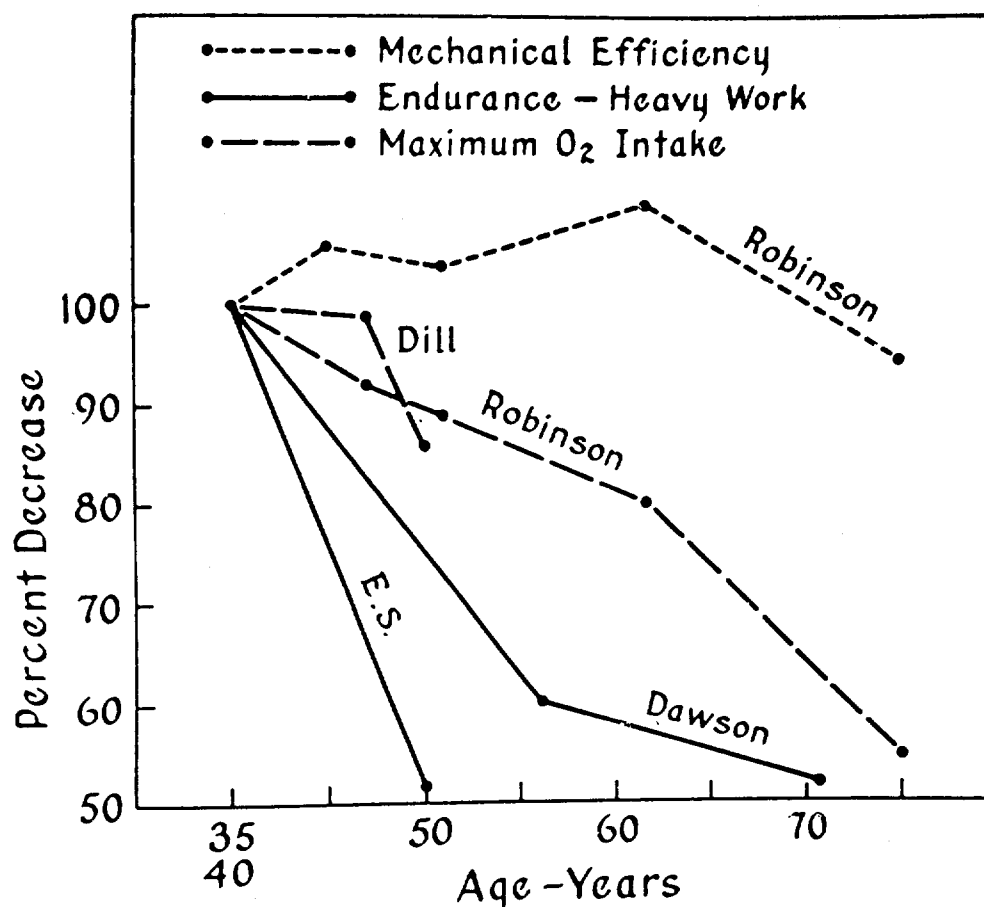


FIGURE 8.—Effects of age on mechanical efficiency in moderate aerobic work (Robinson, 1938), the maximum O_2 intake in aerobic work (Dill, 1942; Robinson, 1938), and endurance in heavy aerobic work (Dawson and Hellebrandt, 1945) expressed in percent of peak performance between 30 and 40 years. (Reproduced with permission from Figure 5 in Simonson, E.: Functional Capacities in Older Individuals, JOURNAL OF GERONTOLOGY, 13:18-26, Supplement No. 2, 1958.)

There is evidence that with aging the influence of the nervous system on a number of organs and body functions is decreased.¹⁹ Several studies recently conducted by Russian scientists indicated that there were age-related modifications in the metabolism of major biochemical transmitters, such as the catecholamines and acetylcholine.⁴⁴ In old age, the biosynthesis of these hormones seemed to be decreased, and this deficiency was followed by a reorganization of their major metabolic pathways. This apparently causes an impairment of the sympathetic activity and delayed adrenergic reactions.

Today, many investigators believe that alterations in the genetic code and protein biosynthesis may be intricately involved in cell aging processes. Loss of control of the regulatory genes may result in the qualitative and quantitative changes, which subsequently bring about aging and death of a cell.⁴⁵

Electrophysiologically, the slowing of the alpha rhythm has been frequently reported as a function of aging, and beta wave activity was found to decline.^{109, 113, 114} The basic age-related change in the electroencephalogram (EEG) occurs predominately along the frequency dimension. The dominant alpha rhythm (8-12 Hz) increases with age at the rate of about 4 milliseconds per cycle per decade. Hence, an increase of about 15 milliseconds per cycle occurs between the ages of 30 and 70 years. There is an accompanying increase in the theta (4-7 Hz) and delta (1-3 Hz) activity. Although fast beta waves (13-25 Hz) are prevalent during early senescence, they become less frequent with old age. Generally, the average frequency spectrum of the EEG in the old is approximately one cycle slower than the comparable young adult curve; the peak frequency of the alpha rhythm in the older persons is typically 9 Hz.⁵⁹

It now appears that the age-associated slowing of RT is closely related to the change in brain-wave activity.⁷¹ Since it has been shown that simple RT depends upon the phase of the alpha cycle in which a stimulus falls, it can be assumed that the increased alpha period may cause the slowing of RT with age. Furthermore, the alpha cycle may very well be implicated in the timing of higher order mental activity, such as information-handling capacity and decision making, which are also adversely affected by aging.

The brain wave pattern of old people was found to be more responsive to physical exercise than that of the young, although it showed a diffuse slowing in cases of advanced senility.^{72, 88} The percentage of REM sleep remains stable until about the age 80 but drops rapidly thereafter.³⁷ Correlations between cognitive and drive functions on amount of REM sleep in the aged indicated that CNS functions are involved in this process.⁵⁵ As to the functions of the autonomic nervous system (ANS), the aged show less responsiveness than the young as indicated by the galvanic skin response (GSR).⁸⁸

In the area of behavioral sciences, there is a definite correlation between the results of neurophysiological tests and chronological age, al-

though there is no evidence of an identifiable disease. However, there was also discovered a striking similarity between the effects of aging and heart disease on psychological test scores, which led to the conclusion that impairment of cardiovascular functions may be responsible to a large degree for the general deterioration of performance capacity with age.⁹⁵ Table 2 shows a survey about the effects of age and cardiovascular disease on various types of human performance.

There is a typical pattern of psychological changes associated with advancing age which has a normal neurophysiological rather than pathogenetic basis. While some investigators found, for example, a correlation of age with both psychomotor speed and blood pressure, age-speed correlation was higher than the age-blood pressure correlation. Hence, they concluded that the trend toward higher blood pressure with advancing age could not be regarded as the cause of slowing down the sensory-motor performance. Instead, it may possibly reflect a common change with advancing age in the regulation of the CNS of autonomic and behavioral functions. Patients with hypertension and those with coronary artery disease appeared to show more psychomotor

TABLE 2. Some Effects of Older Age and Heart Disease on Performance Measures and Related Physiologic Functions (From E. Simonson: Performance as a Function of Age and Cardiovascular Disease. See: A. T. Welford and J. E. Birren, 1965.)^{92, 118}

Performance and Physiologic Functions	Age	Cardiovascular Disease
Max. O ₂ intake	Decreased ⁽¹⁾	Decreased ⁽²⁾
Speed of initial increase of O ₂ in work	Delayed ⁽¹⁾	Delayed ^(2,3)
Oxidative recovery	Delayed ^(1,4,20)	Delayed ^(2,3)
Respiratory efficiency	Decreased ^(1,5,20)	Decreased ⁽²⁾
Cardiac stroke volume	Decreased ⁽⁶⁾	Decreased ^(2,6)
Pulse rate recovery	Delayed ^(1,20)	Delayed ⁽²⁾
Endurance, moderately heavy work	Decreased ^(7,8)	Decreased ⁽²⁾
Muscle strength	Decreased ^(10,11,12)	Unchanged or slightly decreased ⁽¹³⁾
Speed repet. movements, small muscles	Slightly decreased ⁽¹⁴⁾	Moderately decreased ⁽¹⁵⁾
Mechanical efficiency	Unchanged or moderately decreased at higher age ^(1,5)	Unchanged or moderately decreased dependent on degree of decompensation and load ⁽²⁾
Endurance, static work	Unchanged ⁽⁹⁾	Probably little change
Motor coordination; small muscles	Unchanged ^(14,16,17,18)	Probably unchanged
larger muscles	Well maintained ^(19,21)	Probably little changed

- (1) Robinson, 1938
 (2) Reviewed in Simonson and Enzer, 1942
 (3) Meakins and Long, 1927
 (4) König *et al.*, 1952
 (5) Durkin and Mikulicic, 1956
 (6) Landowne *et al.*, 1955
 (7) Dawson and Hellebrandt, 1945

- (8) Burke *et al.*, 1953
 (9) Simonson *et al.*, 1943
 (10) Quetelet, 1836
 (11) Reijis, 1921
 (12) Fisher and Birren, 1947
 (13) Panfilov, 1963
 (14) Kossoris, 1940

- (15) Simonson and Enzer, 1941
 (16) Ascher and Baumgarten, 1928
 (17) Berg, 1947
 (18) Stieglitz, 1941
 (19) Jokl, 1954
 (20) Frel'kis *et al.*, 1965
 (21) Smith, 1938

slowing than would be expected from age alone. The evidence again points to a separation of the effects of disease from a pattern of measurements representative of normal neurophysiological aging.⁹⁵

Several studies of conduction velocity in human motor nerves have shown that the speed of transmission of the nervous impulse is slowed in old age.⁹⁶ However, motor response time seems to be remarkably constant for both young and elderly persons. Slowness or difficulties in perceiving and transmitting a stimulus results, at least partially, in the increase of reaction time as previously pointed out, since speed of perception is an important factor in mental activity: the decreased mental capacity of the elderly, thus, has been explained. The difficulty in accepting sensory input may be related to the inability of the nervous system to perceive and interpret the incoming information, thus failing to maintain an ongoing "neuronal pattern" in the face of fresh stimulus input.¹⁶ This loss of capacity seems to occur at certain critical stages, particularly at about age 40 and again at age 60.¹⁰⁶ There is also an age deficit in coding and registration of stimulus input material leading to a deficit in the retrieval process. Moreover, the rate of loss of immediate memory tends to increase with age; i.e., the storage process underlying the capacity for fast recall is subject to decay.²²

It was concluded from the result of a short-term memory test that the retrieval time became longer with increasing age. This slowing was thought to be brought about by the increased time required to search through the content of memory and to initiate or generate the response.³ In general, the old lose speed and flexibility and lack the kind of reserve and coordination that accounts for maximum performance of the brain.⁵³ The neural deficit in the aged can be largely explained by a decreased number of functionally available neurons, changed cell metabolism, prolonged time for the ideation process, and the loss of speed in the retrieval of memory.

VI. Personality.

The effects of aging as manifested in psychological, mental, and neurophysiological performance or behavior patterns are in themselves related to many alternative conditions and

factors not considered so far. Some alterations of behavior can be caused by or may be associated with changes of the personality, temperament, motivation, or the value system of the individual, or they may depend on some trivial or idiosyncratic elements aroused by the situation. For example, it was observed that attitudes and emotional factors influenced performance on a test of critical thinking ability. Hence, these variables must be taken into account when dealing with the performance of the elderly. The ability to weigh evidence and critically interpret data and changes in deductive thinking in relation to age are graphically displayed in Figure 9.

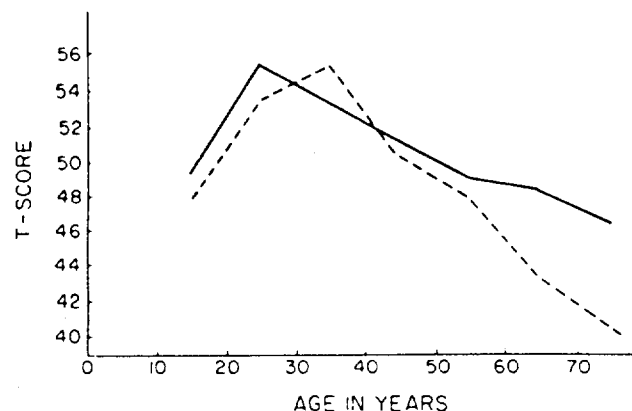


Figure 9.—Results from 484 subjects, age 12–80 years, on the Watson-Glaser Critical Thinking Appraisal Test. The solid line indicates ability to weight evidence and interpret data; the broken line indicates changes in deductive thinking. (Reproduced with permission from Figure 8-1 in Birren, J. E.: *The Psychology of Aging*, Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1964, 300 pp. Original figure in Friend, C. M., and J. P. Zubek: The Effects of Age on Critical Thinking Ability, *JOURNAL OF GERONTOLOGY*, 13:407–413, 1958.)

A significant decrease in all measures of flexibility and a significant increase in all measures of behavioral rigidity with advancing age were reported.⁷⁹ The correlation between the measures of mental abilities and personal rigidity were significant throughout the adult age span with a tendency to decrease toward the upper end of the age continuum. There is also a certain possibility of a relationship among the effects of age, heart disease, and personality test scores, implying that impairment of cardiovascular functions may be to a degree responsible for the general decline of performance capacity with age.¹¹⁸

It has long been assumed that the aged are at a resting state of low internal arousal and sustain a low drive state. However, aged persons were found to function at a relatively high level of autonomic activity (such as blood pressure, heart rate, and respiration) when arousal or anxiety was heightened by situational circumstances.³⁰ For example, the performance of older persons is in jeopardy under hazardous traffic conditions.¹⁰

The effects of differential reinforcement of cautiousness upon intellectual performance in older persons were investigated with respect to such influences.³ Cautiousness is often thought to be a behavioral characteristic very typical of the elderly. Experimentally, this factor was manipulated by systematically varying pretest instructions involving reinforcement at two levels of risk-taking when subjected to the Primary Mental Abilities Test. The results confirm most of the previous observations; namely, that older subjects are usually low risk takers and perform better under such conditions. This became obvious only when they realistically exercised their option of either responding or not responding to the individual task items.

By using the Edwards Personality Preference Schedule, a forced-choice test designed to measure the relative strength of 15 needs derived from Murray's list of manifest needs, highly significant differences between young and old subjects were found on five of these needs.¹⁰⁶ On three items, namely deference, order, and endurance, need scores were higher for the older subjects. On two items, namely, heterosexual activity and exhibition, their scores were lower. Marginally significant were differences indicating lower need for dominance and higher need for abasement on the part of the older group.³

It has been hypothesized that older subjects automatically make most of what capacity they may have, and this process has been defined as "unconscious optimization." Such behavior is often thought to be related to the concept of experience; i.e., the ability of the organism to adjust through learning. In an experiment designed to investigate age differences in developing the optimum strategy for finding the malfunction in a broken-down machine, older persons did not show any change of their approach to the problem with increasing time on

the test, whereas younger subjects did improve, indicating a greater selectivity and adaptability than the older ones. This was also true in a guessing-type experiment. Once again, the old subjects showed less of an optimization tendency than the younger ones. Not only did the older persons behave suboptimally, but their performance fell below that of the youngsters, although the older ones had more to lose.⁸⁴

Moral development and moral judgment in the elderly have been found to be curvilinearly related to chronological age. Moral judgment rose from a relatively low level in preadolescents to the highest level in the middle-aged adults.⁴² Thereafter, average stage levels declined. This trend was thought to be caused by the elderly persons' decreased ability to apply their environmental experiences to their moral judgments. It also was theorized that variability in the moral judgments of the elderly could be the result of an identity crisis associated with aging, the social isolation of the aged, and the onset of senility. Figure 10 shows how four selected components of social age change during a period of four decades.⁴¹ The analysis of egocentrism as related to aging has been based primarily on results of perceptual or spatial tests. Elderly subjects showed wide individual differences in their ability to decenter and decrease spatial egocentrism task performance as compared to younger ones.⁴³ In another comparative age study, a curvilinear relationship was found between spatial and communicative egocentrism and chronological age.⁸³ Finally, a study will be mentioned in which age estimates were based on the psychological assessment of personality variables. Scores from the Cattell Sixteen Personality Factor Questionnaire (16 PF) were used to predict the chronological age of subjects and to study the relationships among the ages predicted from these measures. It was stated in this context that the assessment of a man's personality in terms of a functional age index may also be of a practical value for determining career endpoints and retirement planning.⁴⁰

It was found by an analysis of the 16 PF that scores from three of the 16 primary factors accounted for 8 percent of the variance of predicted age, namely surgency (F), self-sentiment (Q₃), and sensitivity (I). A formula expressing

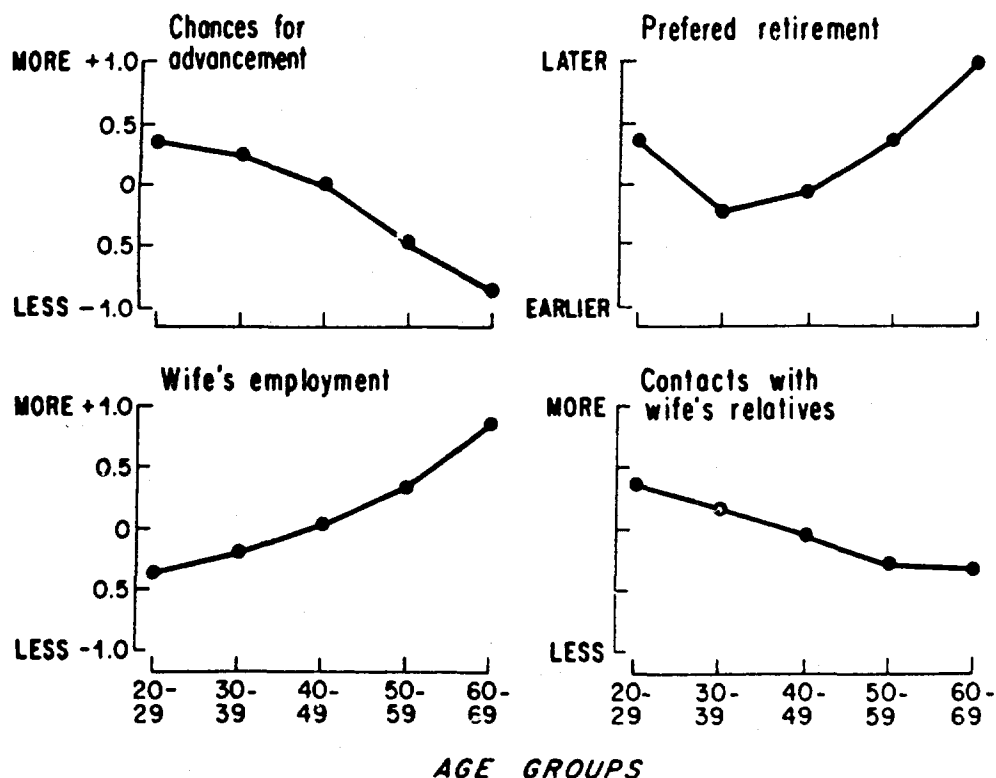


FIGURE 10.—Age changes in mean values (standardized units) of four selected components of social age. (Reproduced with permission from Figure 1 in Rose, C. L.: *The Measurement of Social Age, AGING AND HUMAN DEVELOPMENT*, 3:153-168, 1972.)

the relationship of these factors was given by the investigator:

Personality age =

$$-2.21 \text{ Factor F} + 0.25 \text{ Factor } Q_3 + 0.21 \text{ Factor I} + 39.17$$

The differences with age in the means of the measures of the three personality factors are given in Figure 11 (right-hand side). The most significant ability measures which were part of this experiment are shown on the left side. Scores on the most important variable, Factor F (surgency vs. desurgency), show a tendency toward less surgency in older subjects; i.e., they are sober, taciturn, and serious. Scores on Factor Q_3 (self-sentiment) tends towards higher degrees of self-sentiment in the aged; i.e., they are thought to be more controlled, exacting, and socially precise. Scores on Factor I ("premsia") indicates a greater sensitivity with increasing age.¹⁷ Figure 11 also shows that in comparison with the ability scores the age differences on the personality scale are relatively small. Moreover, four of the curves have their maximum rate of change during the two highest age ranges.⁴⁰

Using a somewhat different approach, other investigators identified the factors C, F, G, I, and M of the 16 PF as remaining relatively stable, with unsystematic age trends for the remaining factors.⁴⁸

By and large, the results of this analysis are in agreement with previous observations that some aspects of the personality structure and some of the personality traits are relatively stable, while others change with age.

Accidents. Probably the greatest practical implications of human aging in the context of this treatise are in the area of personal and public safety, since older persons tend to have high rates of accidents.⁴ In a related study, the average annual death rates from motorcycle accidents were analyzed for the years 1926-1928 and at decennial intervals until 1966-1968 using six age groups. While the total number of motor vehicle fatalities steadily decreased with age for persons 15-44 years old, the rate generally increased from age 45 on, reaching its maximum with the oldest age groups. Only the 15-25 year-old males exceeded this group in the two latest samples.

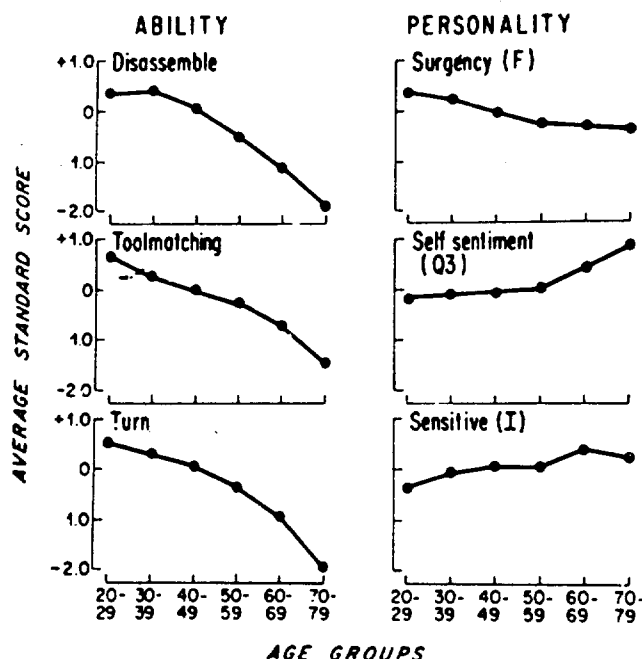


FIGURE 11.—Age changes in the means of three measures of ability and three measures of personality that Fozard found to be significant predictors of chronological age.⁶ (Reproduced with permission from Figure 1 in Fozard, J. L.: Predicting Age in the Adult Years From Psychological Assessment of Abilities and Personality, *AGING AND HUMAN DEVELOPMENT*, 3:175-182, 1972.)

Detailed studies of the nature and cause of accidents have shown that those sustained by younger people are often due to carelessness or foolhardy behavior, whereas accidents of older people tend to be caused by slowness in anticipating hazards or in taking action to avoid them.⁷⁸ While it is recognized that circumstances and risks are the main determinants of accidents, age can cause small differences in coping with ensuing situations which may substantially determine the outcome of a hazardous situation.

VII. Aging and the Human Pilot.

The process of aging is of a greater significance for pilots than for most other occupational groups because of the exacting demands of their job. As a pilot grows older, the alterations in physical and mental fitness may greatly influence his professional efficiency. Early detection of deteriorations in psychophysiological functions and performance of airline pilots is imperative to flight safety. Therefore, aeromedical investigations were conducted in this country and

abroad to determine the effects of age-related changes in older pilots and to assess their implications.¹¹⁹

A. *Performance Measures.* In an early study (1953) on U.S. Air Force pilots using the "critical-incident technique," it was found that the physical abilities of aircrew members decreased with age, particularly the ability to resist fatigue and sustained demands upon the human organism.⁸⁹ Actual job performance deteriorated particularly with respect to speed and accuracy of work and corrective action, control in emergency situations, and—surprisingly—retention of a proportionate degree of caution. There were some indications that the relationships of the older crewmembers with the rest of the team became poorer. Also, the ability and motivation to improve in skill and technique were found to decline, and motivation and adjustment in regard to the job in general were negatively age related.

In later investigations conducted by scientists in the U.S.S.R. on two groups of pilots (30-39 years and 40-50 years), no differences between these groups were found concerning simple RT and speed of the "basic nervous processes."¹⁸ There was no impairment of short-term visual memory in the older subjects. There was also no decrease in the interpretation of visual stimuli, and no differences were found in the information-processing ability between the younger and older pilots.

It was reported, however, that the older pilots needed longer times to shift their attention and that the overall performance declined with increasing age at the higher levels of information input. Nonetheless, the older pilots seemed to adopt a more efficient strategy in signal detection; it was thought that this outweighed, at least partially, some of the limitations imposed by the peripheral end of the visual pathway. The results of a longitudinal aging study on pilots conducted by the Lovelace Foundation for Medical Research and Education showed that visual accommodation, dark adaptation, and auditory functions are impaired with age.⁷³

In a sampling of over 100 professional pilots, it was suspected and concluded that their responses to sudden emergencies under conditions of information overload became less and less adequate as they grew older.¹⁰⁰ It is equally clear that, insofar as skill proficiency can ever

be evaluated outside the actual flying situation, the routine aspects of the professional pilot's skills seem likely to be affected by aging. It was reported that pilots over age 40 are relatively more susceptible than the younger ones to the effects of information overload when other activities intervene during the period of information acquisition.¹⁰¹

It is difficult to find dependable criteria by which the effects of experience, such as judgment, insight, and comprehension of the task on performance, can be measured. The subjective assessment of job performance indicates that the overwhelming majority of older pilots do not notice increased weariness during routine duties or transit training nor show forgetfulness, absent-mindedness, or ineffective performance in flight.⁵⁴ However, it was found that the restoration of "higher nervous activity" after extended flights (10 hours) to the original level took longer in the older pilots than in the younger ones. This was demonstrated by the EEG records obtained from the older pilot group.

B. Neural Functions. The analysis of clinical and physiological functions of senior pilots of the civil air fleet in the U.S.S.R. yielded very delicate changes in the motor coordination in pilots over 45 years of age.⁵⁴ The higher nervous activity, visual discrimination, and some psychological functions showed that the older pilots were not as readily adaptable to new situations as the younger ones. In contrast, they appeared to be psychologically more stable. Although visual memory did not deteriorate with age, their capacity and concentration of attention tended to decrease slightly. The functions of the vestibular apparatus of the inner ear and its effects on motion sensitivity and motion sickness were unrelated to age.

Measures of "reserve channel capacity" and psychophysiological thresholds revealed that, in a sample of 250 active pilots, age differences were less impressive than would be expected from gerontological studies on the general population.¹⁰² However, "overload conditions" of the information channels indicated a small but consistent negative correlation with age. This condition has been interpreted as an increased noise level in the central nervous system of the older pilots.

C. Medical and Psychological Interactions. It also seems that the individual differences among airmen in some of the relevant modalities of performance are related to their cardiovascular status.¹⁰³ This suggests that the performance degradations in a high-grade skill are more likely to depend upon the age-related efficiency of the pulmonary and cardiovascular system than upon age as such. Persons suffering from arteriosclerotic coronary heart diseases or showing evidence of old myocardial infarctions and those with essential hypertension performed more poorly on a wide variety of psychological tests than did reasonably well-matched, healthy subjects.¹⁰⁴ The incidence of cardiovascular diseases and their increase with age are high enough to account for much of the decline of psychological and mental functions in older pilots. However, there is undoubtedly much more to aging than cardiovascular or other related diseases.⁹⁵

D. Age and Aircraft Accidents. In a 1967 FAA report concerning aircraft accidents by older persons, it was reported that total accident rate is lowest for the age group 16-29 years, highest for the age group 30-43 years, declines for the group 44-59 years and rises only slightly for ages 60 and older.^{60, 63} However, more recent statistical analyses of accident data revealed that the accident rate increases quite rapidly after age 59 and reaches its maximum after age 70 as shown in Figure 12. Such data, however, must be interpreted in terms of the "exposure time" of subjects in each age group.

VIII. Summary and Conclusions.

Human aging is a biological process with profound implications on performance and proficiency. Although there is evidence that the occurrence of cardiovascular incapacitation and the number of accidents and deaths in aviators increase drastically after age 60, the actual cutoff point of the pilot's career due to aging has not been scientifically established. In order to arrive at some reliable criteria for retirement from flight, large numbers of pilots have been studied in the past in several countries through medical examinations and by physiological and psychological tests. In the United States, there were three longitudinal studies conducted on airmen, of which the One-Thousand-Aviator-Study is

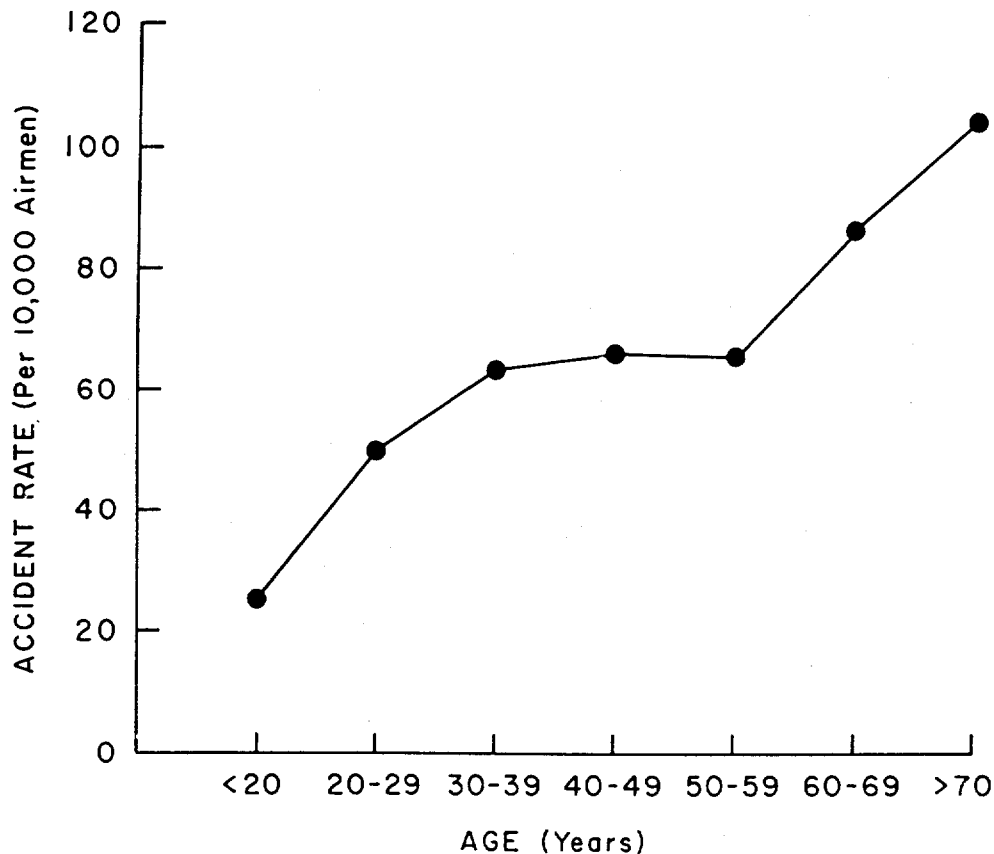


FIGURE 12.—Age and accident rates in general aviation pilots (1974 data).

still pursued at the U.S. Naval Aerospace Medical Center in Pensacola, Florida. However, the attempt to assess the pilot's critical functional changes due to aging in the rapidly changing aviation environment over long periods of time and to apply the findings to the determination of career endpoints presents formidable methodological and practical obstacles.

Different approaches have therefore been used to determine the physiological and psychological effects of aging and their relationships with flight safety. In 1953, a study conducted by the American Institute of Research for the United States Air Force was published, in which the critical incident technique was used to define behavior that was thought to be affected by age. Five years later, scientists developed a battery of psychophysiological tests for the assessment of age-related changes in aircrew performance. It was found that the physical abilities of the crewmembers decreased with age, particularly the capacity of the human organism to resist fatigue and sustained demands. Measures of mental and neural functions taken by scientists

at the Lovelace Foundation for Medical Education and Research on a sample of 250 active pilots showed that reserve channel capacity and task overload conditions correlated negatively with age, the fact notwithstanding that most of the pilots were below the age 60. By and large, systematic investigations and factor analyses concerning functional age changes and aviator proficiency of older pilots are not aplenty.

In the area of behavioral sciences, psychometric measures have been used successfully for assessing age differences. Excellent surveys of the state of the art were given by Dennis (1953) and recently by Schaie and Gribbin (1975).^{28, 83} The latter concluded that the psychology of aging has matured a great deal during the past 5 years. There has been a significant shift of interest from measuring differences towards the direct explication of age changes by means of descriptive as well as experimental strategies. Moreover, dissatisfaction with chronological age as the independent variable in gerontological studies has led to an examination of the concept of functional age. Functional age would be a

convenient method to apply to problems of variable retirement. The wealth of information available in the fields of experimental psychology, applied physiology, and gerontology can be consulted in this effort. They show age-related decreases in a wide variety of functions, such as reaction time, memory, complex performances, manual skills, visual, tactile and auditory perception, cognitive and mental abilities, learning and other processes in different population samples including experienced pilots.

Generally, abilities to perform highly skilled tasks rapidly, to adapt to new and changing environmental situations, to resist fatigue, to maintain physical stamina, and to perform effectively in a complex and stressful environment begin to decline in early middle life and continue to decline at a fairly steady rate thereafter.

One of the most critical requirements in regard to pilot performance—namely, information processing—is jeopardized in older pilots because of the risk of “overloading” of the channel capacity of the central nervous system. The extent to

which retained experience, judgment, and reasoning abilities tend to counteract the functions which do deteriorate has not been adequately determined. The point which is critical is that at which the compensatory mechanisms fail to neutralize the deteriorated functions in older pilots. The piloting of aircraft then may become hazardous. The studies reported and reviewed fail to indicate how that point can be identified.

There is no “psychophysiologic age index” available that can be reliably applied for determining the performance of airline pilots. However, the development of such an index appears feasible and therefore should be pursued. At present, the psychophysiologic cutoff point of the age-related performance-degradation curve for pilots has not been determined. The findings of this survey suggest that some of the critical functions deteriorate during the sixth decade: some persist after the age 60 is reached. As a provisory solution to the age problem in the cockpit, it is recommended that older captains should always be paired with younger pilots.

References

1. Abrahams, J. P., and J. E. Birren: Reaction Time as a Function of Age and Behavioral Predisposition to Coronary Heart Disease, *JOURNAL OF GERONTOLOGY*, 28:471-478, 1973.
2. Adamowicz, J. K.: Visual Short-Term Memory and Aging, *JOURNAL OF GERONTOLOGY*, 31:39-46, 1976.
3. Anders, T. R., J. L. Fozard, and T. D. Lillyquist: The Effect of Age Upon Retrieval From Short-Term Memory, *DEVELOPMENTAL PSYCHOLOGY*, 6:214-217, 1972.
4. Anonymous: Metropolitan Life, *STATISTICAL BULLETIN*, 52:5-8, 1971.
5. Bell, B.: Significance of Functional Age for Interdisciplinary and Longitudinal Research on Aging, *AGING AND HUMAN DEVELOPMENT*, 3:145-147, 1972.
6. Bell, B.: Auditory Functional Age, *AGING AND HUMAN DEVELOPMENT*, 3:183-187, 1972.
7. Bell, B., E. Wolf, and C. D. Bernholz: Depth Perception as a Function of Age, *AGING AND HUMAN DEVELOPMENT*, 3:77-81, 1972.
8. Bergman, M.: Changes of Hearing With Age, *GERONTOLOGIST*, 11:148-151, 1971; Hearing and Aging: Implications of Recent Research Findings, *AUDIOLOGY*, 10:164-171, 1971.
9. Birkhill, W. R., and K. W. Schaie: The Effects of Differential Reinforcement of Cautiousness in Intellectual Performance Among the Elderly, *JOURNAL OF GERONTOLOGY*, 30:578-583, 1975.
10. Birren, J. E.: *The Psychology of Aging*, Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 1964, 300 pp.
11. Birren, J. E., R. N. Butler, S. W. Greenhouse, L. Sokoloff, and M. R. Yarrow: *Human Aging*. Public Health Publication No. 986, pp. 132-137, 1963.
12. Botwinick, J., R. West, and M. Storandt: Qualitative Vocabulary Test Response and Age, *JOURNAL OF GERONTOLOGY*, 30:574-577, 1975.
13. Braun, H. W.: Perceptual Processes. In Birren, J. E. (Ed.), *Handbook of Aging and the Individual*. Chicago, University of Chicago Press, 1959, 939 pp.
14. Brinley, J. F.: Cognitive Sets, Speed and Accuracy of Performance in the Elderly. In Welford, A. T., and J. E. Birren (Eds.), *Behavior, Aging, and the Nervous System*. Springfield, Illinois, Charles C. Thomas, 1965, 637 pp.
15. Bruning, R. H., J. Holzbauer, and C. Kimberlin: Age, Word Imagery, and Delay Interval: Effects on Short-Term and Long-Term Retention, *JOURNAL OF GERONTOLOGY*, 30:213-318, 1975.
16. Canestrari, R. E.: Age Changes in Acquisition. In Talland, G. A. (Ed.), *Human Aging and Behavior*. New York, Academic Press, 1968, 322 pp.
17. Cattell, R. B.: *Personality: A Systematic, Theoretical, and Factual Study*. New York, McGraw-Hill, 1950.
18. Chapek, A. V., V. P. Yerokhin, and I. P. Poleschuk: The Influence of Age-Associated Changes in Older Pilots During Relearning in the New Aviation Technology and During Performance, *AVIATION AND SPACE MEDICINE*, 419-421, 1964.
19. Chebotarev, D. F., and V. V. Frolkis: Research in Experimental Gerontology in the USSR, *JOURNAL OF GERONTOLOGY*, 30:441-447, 1975.
20. Clark, L. E., and J. B. Knowles: Age Differences in Dichoptic Listening Performance, *JOURNAL OF GERONTOLOGY*, 28:173-178, 1973.
21. Corso, C. F.: Sensory Processes and Age Effects in Normal Adults, *JOURNAL OF GERONTOLOGY*, 26:90-105, 1971.
22. Craik, F. I. M.: Short-Term Memory and the Aging Process. In Talland, G. A. (Ed.), *Human Aging and Behavior*. New York, Academic Press, 1968, 322 pp.
23. Crossman, E. R. F. W., and J. Szafran: Changes With Age in the Speed of Information Intake and Discrimination, *EXPERIENTIA*, Supplement 4:128-135, 1956.
24. Crouch, E. L.: The Relation Between Illumination and Vision, *ILLUMINATION ENGINEERING*, 40:747-784, 1945.
25. Dastur, D. K., M. H. Lane, D. B. Hansen, S. S. Kety, R. N. Butler, S. Perlin, and L. Sokoloff: Effects of Aging on Cerebral Circulation and Metabolism in Man. In Birren, J. E., R. N. Butler, S. W. Greenhouse, L. Sokoloff, and M. R. Yarrow (Eds.), *Human Aging*. Public Health Publication No. 986, 1963.
26. Davies, D. R.: Age Differences in Paced Inspection Tasks. In Talland, G. A. (Ed.), *Human Aging and Behavior*. New York, Academic Press, 3-22, 1968.
27. Dempster, A. P.: Functional Age and Age-Related Measures, *AGING AND HUMAN DEVELOPMENT*, 3:195-196, 1972.
28. Dennis, W.: Age and Behavior—A Survey of the Literature. USAF School of Aviation Medicine, Randolph Field, Texas, P. No. 21-0202-0005, 1953.
29. Drachman, D. A., and J. Leavitt: Memory Impairment in the Aged: Storage Versus Retrieval Deficit, *JOURNAL OF EXPERIMENTAL PSYCHOLOGY*, 93:302-308, 1972.

30. Eisdorfer, C.: Arousal and Performance: Experiments in Verbal Learning and a Tentative Theory. In Talland, G. A. (Ed.), *Human Aging and Behavior*, New York, Academic Press, 1968, 322 pp.
31. Eisdorfer, C., J. Nowlin, and F. Wilkie: Improvement of Learning in the Aged by Modification of Autonomic Nervous System Activity, *SCIENCE*, 170:1327-1329, 1970.
32. Elias, M. F., and M. Kinsbourne: Age and Sex Differences in the Processing of Verbal and Non-Verbal Stimuli, *JOURNAL OF GERONTOLOGY*, 29:162-171, 1974.
33. Erwin, D. E., and J. F. Fozard: Paced Inspection Performance in Older Subjects. Paper presented at the Annual Meeting of the Eastern Psychological Association, New York, April 1971.
34. Eysenck, M. W.: Retrieval From Semantic Memory as a Function of Age, *JOURNAL OF GERONTOLOGY*, 30:174-180, 1975.
35. Farrimond, T.: Visual and Auditory Performance Variations With Age: Some Implications, *AUSTRALIAN JOURNAL OF PSYCHOLOGY*, 19:193-201, 1967.
36. Feinberg, A., and E. Podolak: Latency of Pupillary Reflex to Light Stimulation and Its Relationship to Aging. FAA Office of Aviation Medicine Report No. 65-25, 1965.
37. Feinberg, J.: Effects of Age on Human Sleep Patterns. In Kales, A. (Ed.), *Sleep Physiology and Pathology*, Philadelphia, Lippincott, 1969.
38. Fisher, J.: Competence, Effectiveness, Intellectual Functioning and Aging, *GERONTOLOGIST*, 13:62-68, 1973.
39. Foulds, G. A., and J. C. Raven: Normal Changes in the Mental Abilities of Adults as Age Advances, *JOURNAL OF MENTAL SCIENCE*, 94:123-142, 1948.
40. Fozard, J. L.: Predicting Age in the Adult Years From Psychological Assessment of Abilities and Personality, *AGING AND HUMAN DEVELOPMENT*, 3:175-182, 1972.
41. Fozard, J. L., and G. D. Carr, Jr.: Age Differences and Psychological Estimates of Abilities and Skills, *INDUSTRIAL GERONTOLOGY*, 13:75-96, 1972.
42. Fozard, J. L., and R. L. Nuttall: General Aptitude Test Battery Scores for Men Differing in Age and Socioeconomic Status, *JOURNAL OF APPLIED PSYCHOLOGY*, 55:372-379, 1971.
43. Fozard, J. L., R. L. Nuttall, and N. C. Waugh: Age-Related Differences in Mental Performance, *AGING AND HUMAN DEVELOPMENT*, 3:19-43, 1972.
44. Frolkis, V. V.: Regulation, Adaptation and Aging. Nauka, Leningrad, USSR, 1970.
45. Frolkis, V. V., V. V. Bezrukov, Y. K. Duplenko, and E. D. Genis: The Hypothalamus in Aging, *EXPERIMENTAL GERONTOLOGY*, 7:169-184, 1972.
46. Furry, C. A., and P. B. Baltes: The Effect of Age Differences in Ability-Extraneous Performance Variables on the Assessment of Intelligence in Children, Adults, and the Elderly, *JOURNAL OF GERONTOLOGY*, 28:73-80, 1973.
47. Gilbert, J. G.: Thirty-Five Year Follow-Up Study of Intellectual Functioning, *JOURNAL OF GERONTOLOGY*, 28:68-72, 1973.
48. Goodwin, K. S., and K. W. Schaie: Age Differences in Personality Structure, *PROCEEDINGS OF THE 77TH ANNUAL CONVENTION OF THE AMERICAN PSYCHOLOGICAL ASSOCIATION*, 4:713-714, 1969.
49. Green, R. F., and G. Reimanis: The Age-Intelligence Relationship: Longitudinal Studies Can Mislead, *INDUSTRIAL GERONTOLOGY*, 1-16, Summer 1970.
50. Griew, S.: Age, Information Transmission and the Positional Relationship Between Signals and Responses in the Performance of a Choice Task, *ERGONOMICS*, 7:267-277, 1964.
51. Howell, S. C.: Age, Familiarity and Complexity as Recognition Variables, *PERCEPTUAL AND MOTOR SKILLS*, 34:732-734, 1972.
52. Hoyer, W. J., G. V. Labouvie, and P. B. Baltes: Modification of Response Speed Deficits and Intellectual Performance of the Elderly, *HUMAN DEVELOPMENT*, 16:233-242, 1973.
53. Inglis, J.: Immediate Memory, Age and Brain Function. In Welford, A. T., and J. E. Birren (Eds.), *Behavior, Aging, and the Nervous System*, Springfield, Illinois, Charles C. Thomas, 1965, 637 pp.
54. Isaaky, L. S., D. S. Kuleshov, A. V. Chapek, V. M. Kozin, A. N. Ustenova, N. M. Kulekova, Y. I. Kuznetsova, and A. A. Sheshova: Some Results of a Clinical and Physiological Study of Senior Pilots of the Civil Air Fleet, *AVIATION AND SPACE MEDICINE (NASA TTF-228)*, 184-187, 1963.
55. Kahn, E., and C. Fisher: The Sleep Characteristics of the Normal Aged Male, *JOURNAL OF NERVOUS AND MENTAL DISORDERS*, 148:477-494, 1969.
56. Kirsner, K.: Developmental Changes in Short-Term Recognition Memory, *BRITISH JOURNAL OF PSYCHOLOGY*, 63:109-117, 1972.
57. Kline, D. W., and J. Szafran: Age Differences in Backward Monoptic Visual Noise Masking, *JOURNAL OF GERONTOLOGY*, 30:307-311, 1975.
58. Koga, Y., and G. M. Morant: On the Degree of Association Between Reaction Times in the Case of Different Senses, *BIOMETRICA*, 15:346-372, 1923.
59. Kovac, D.: From Reaction Time to the Measuring of Promptness, *ACTA PSYCHOLOGICA*, 30:75-83, 1969.
60. Lategola, M. T., V. Fiorica, C. F. Booze, and E. D. Folk: Comparison of Status Variables Among Accident and Non-Accident Airmen From the Active Airman Population. FAA Office of Aviation Medicine Report No. 70-18, 1970.

61. McFarland, R. A.: The Problem of Aging at Altitude, *YALE SCIENCE MAGAZINE*, pp. 20-28, 1968 (January).
62. Melton, C. E., and M. Wicks: Pilot Vision Considerations: The Effect of Age on Binocular Fusion Time. FAA Office of Aviation Medicine Report No. 66-35, 1966.
63. Mohler, S. R., R. H. S. Bedell, A. Ross, and E. J. Veregge: Aircraft Accidents by Older People. FAA Office of Aviation Medicine Report No. 67-22, 1967.
64. Murrell, V. F. H., and S. Griew: Age, Experience and Speed of Response. In Welford, A. T., and J. E. Birren (Eds.), *Behavior, Aging, and the Nervous System*, Springfield, Illinois, Charles C. Thomas, 1965, 637 pp.
65. Nerke, M. F.: Age and Sex Differences in Discrimination Learning and Transfer of Training, *JOURNAL OF GERONTOLOGY*, 28:320-327, 1973.
66. Noble, C. E.: Age and Sex Parameters in Psychomotor Learning, *PERCEPTUAL AND MOTOR SKILLS*, 19:335-345, 1964.
67. Noble, C. E.: Acquisition of Pursuit Tracking Skill Under Extended Training as a Joint Function of Sex and Initial Ability, *JOURNAL OF EXPERIMENTAL PSYCHOLOGY*, 86:360-373, 1970.
68. Nuttall, R. L.: The Strategy of Functional Age Research, *AGING AND HUMAN DEVELOPMENT*, 3:149-152, 1972.
69. Nuttall, R. L., and J. L. Fozard: Age, Socioeconomic Status and Human Abilities, *AGING AND HUMAN DEVELOPMENT*, 1:161-169, 1970.
70. Obrist, W. D.: The Electroencephalogram of Healthy Aged Males. In Birren, J. E., R. N. Butler, S. W. Greenhouse, L. Tokoloff, and M. R. Yarrow (Eds.), *Human Aging*, Public Health Publication No. 986, 1963.
71. Obrist, W. D.: Electroencephalographic Approach to Age Changes in Response Speed. In Welford, A. T., and J. E. Birren (Eds.), *Behavior, Aging, and the Nervous System*, Springfield, Illinois, Charles C. Thomas, 1965, 637 pp.
72. Obrist, W. D., E. Chivian, S. Cronquist, and D. H. Ingvar: Regional Cerebral Bloodflow in Senile and Presenile Dementia, *NEUROLOGY*, 20:315-322, 1970.
73. Papalia, D. E.: The Status of Several Conservative Abilities Across the Life-Span, *HUMAN DEVELOPMENT*, 15:229-243, 1972.
74. Papalia, D. E., and D. del Vento Bielby: Cognitive Functioning in Middle and Old Age Adults, *HUMAN DEVELOPMENT*, 17:424-443, 1974.
75. Proper, R.: Study of Physiologic and Psychologic Aging in Pilots, Progress Report. National Institute of Health Grant No. HD-00518, The Lovelace Foundation for Medical Education and Research, Albuquerque, New Mexico, June 1969.
76. Rabbitt, P. M. A.: Set and Age in a Choice-Response Task, *JOURNAL OF GERONTOLOGY*, 19:301-306, 1964.
77. Rabbitt, P. M. A., and M. Rogers: Age and Choice Between Responses in a Self-Paced Repetitive Task, *ERGONOMICS*, 8:435-444, 1965.
78. Reese, F. B.: Motor Vehicle Accident Deaths in the United States, 1950-67. National Center for Health Statistics Report No. 9, 1970.
79. Riegel, K. F.: Personality Theory and Aging. In Birren, J. E. (Ed.), *Handbook of Aging and the Individual*, Chicago, The University of Chicago Press, 1959, 939 pp.
80. Riegel, K. F., and J. E. Birren: Age Differences in Choice Reaction Time to Verbal Stimuli, *GERONTOLOGIA*, 13:1-13, 1967.
81. Rose, C. L.: The Measurement of Social Age, *AGING AND HUMAN DEVELOPMENT*, 3:153-168, 1972.
82. Roscoe, B., Graf de la: Untersuchung uber das normale Horvermogen in den verschiedenen Lebensaltern unter besonderer Berucksichtigung der Prufung mit Gera. Audiometer, *ZEITSCHRIFT FUR LARYNGOLOGIE, RHINOLOGIE, OTOLOGIE U. IHRE GRENZGEBIETE*, 32:414-420, 1953.
83. Rubin, K. H., P. W. Attewell, M. C. Tierney, and P. Tumolo: Development of Spatial Egocentrism and Conversation Across the Life Span, *DEVELOPMENTAL PSYCHOLOGY*, 9:432-437, 1973.
84. Sanford, A. J., and A. J. Mantle: The Concept of Experience: Age and Strategies in Guessing Future Events, *JOURNAL OF GERONTOLOGY*, 28:81-88, 1973.
85. Schaie, K. W., and K. Gribbin: Adult Development and Aging. In Rosenzweig, M. R., and L. W. Porter (Eds.), *Annual Review of Psychology*, 26:65-96, 1975.
86. Schaie, K. W., G. V. Labouvie, and T. J. Barrett: Selective Attrition Effects in a Fourteen-Year Study of Adult Intelligence, *JOURNAL OF GERONTOLOGY*, 28:328-334, 1973.
87. Schaie, K. W., and C. R. Strother: Cognitive and Personality Variables in College Graduates of Advanced Age. In Tolland, G. A. (Ed.), *Human Aging and Behavior*, New York, Academic Press, 1968, 322 pp.
88. Shmavonian, B. M., L. H. Miller, and S. E. Cohen: Differences Among Age and Sex Groups With Respect to Cardiovascular Conditioning and Reactivity, *JOURNAL OF GERONTOLOGY*, 25:87-94, 1970.
89. Shriver, B. M.: Age and Behavior—A Study of the Effects of Aging on Aircrew Performance. USAF School of Aviation Medicine, Randolph Field, Texas, February 1953.
90. Silverman, I.: Age and the Tendency to Withhold Response, *JOURNAL OF GERONTOLOGY*, 18:372-375, 1963.
91. Simon, J. R.: Translation Processes and Aging, *PSYCHONOMIC SCIENCE*, 9:553-553, 1967.
92. Simon, J. R.: Choice Reaction Time as a Function of Auditory S-R Correspondence, Age and Sex, *ERGONOMICS*, 10:659-664, 1967.

93. Simonson, E.: Performance as a Function of Age and Cardiovascular Disease. In Welford, A. T., and J. E. Birren (Eds.), *Behavior, Aging, and the Nervous System*, Springfield, Illinois, Charles C. Thomas, 1965, 637 pp.
94. Smith, A. D.: Aging and Interference With Memory. *JOURNAL OF GERONTOLOGY*, 30:319-325, 1975.
95. Spieth, W.: Slowness of Task Performance and Cardiovascular Diseases. In Welford, A. T., and J. E. Birren (Eds.), *Behavior, Aging, and the Nervous System*, Springfield, Illinois, Charles C. Thomas, 1965, 637 pp.
96. Spirduso, W. W.: Reaction and Movement Time as a Function of Age and Physical Activity Level. *JOURNAL OF GERONTOLOGY*, 28:435-440, 1973.
97. Steinberg, F. U., and A. L. Graber: The Effect of Age and Peripheral Circulation on the Perception of Vibration. *ARCHIVES OF PHYSICAL MEDICINE AND REHABILITATION*, 1963.
98. Surwillo, W. W.: Timing of Behavior in Senescence and the Role of the Central Nervous System. In Talland, G. A. (Ed.), *Human Aging and Behavior*, New York, Academic Press, 1968, 322 pp.
99. Surwillo, W. W., and R. E. Chilter: Vigilance, Age and Response Time. *AMERICAN JOURNAL OF PSYCHOLOGY*, 77:614-620, 1964.
100. Szafran, J.: Psychological Studies of Aging in Pilots. *AEROSPACE MEDICINE*, 40:543-553, 1969.
101. Szafran, J.: "Neural Noise" as a Factor Limiting "Channel Capacity." *BIOMEDICAL SCIENCES ENGINEERING*, 4:171-178, 1968.
102. Szafran, J.: Age Differences in Sequential Decisions and Cardiovascular Status Among Pilots. *AEROSPACE MEDICINE*, 36:303-310, 1965.
103. Szafran, J.: Age, Cardiac Output and Choice-Reaction Time. *NATURE*, 209:836, 1966.
104. Szafran, J.: Age Differences in Choice-Reaction Time and Cardiovascular Status Among Pilots. *NATURE*, 200:904-906, 1966.
105. Talland, G. A.: Age and the Span of Immediate Recall. In Talland, G. E. (Ed.), *Human Aging and Behavior*, New York, Academic Press, 1968, 322 pp.
106. Talland, G. A.: *Human Aging and Behavior*, New York, Academic Press, 1968, 322 pp.
107. Taub, H. A.: Memory Span, Practice and Aging. *JOURNAL OF GERONTOLOGY*, 28:335-338, 1973.
108. Taub, H. A.: Mode of Presentation, Age, and Short-Term Memory. *JOURNAL OF GERONTOLOGY*, 30:56-59, 1975.
109. Taub, H. A., and M. K. Long: The Effect of Practice on Short-Term Memory of Young and Old Subjects. *JOURNAL OF GERONTOLOGY*, 27:494-499, 1972.
110. Thompson, L. W., and G. R. Marsh: Psychophysiological Studies in Aging. In Eisdorfer, C., and M. P. Lawton (Eds.), *The Psychology of Adult Development and Aging*, American Psychological Association, Washington, D.C., 1973.
111. Thompson, L. W., E. Opton, Jr., and L. D. Cohen: Effects of Age, Presentation Speed, and Sensory Modality on Performance of a "Vigilance" Task. *JOURNAL OF GERONTOLOGY*, 18:366-370, 1963.
112. Tolin, P., and J. R. Simon: Effects of Task Complexity and Stimulus Duration on Perceptual-Motor Performance of Two Disparate Age Groups. *ERGONOMICS*, 11:283-290, 1968.
113. Wang, H. S., and E. W. Busse: EEG of Healthy Old Persons—A Longitudinal Study: I. Dominant Background Activity and Occipital Rhythm. *JOURNAL OF GERONTOLOGY*, 24:419-426, 1969.
114. Waugh, N. C., J. L. Fozard, G. A. Talland, and D. E. Erwin: Effects of Age and Stimulus Repetition on Two-Choice Reaction Time. *JOURNAL OF GERONTOLOGY*, 28:466-470, 1973.
115. Weekowicz, T. E., R. W. Nutter, D. G. Cruise, and K. A. Yonge: Speed in Test Performance in Relation to Depressive Illness and Age. *CANADIAN PSYCHIATRIC ASSOCIATION JOURNAL*, 17:88-241-250, 1972.
116. Welford, T. A.: Psychomotor Performance. In Birren, J. E. (Ed.), *Handbook of Aging and the Individual*, Chicago, The University of Chicago Press, 1959, 939 pp.
117. Welford, A. T.: Speed and Accuracy of Movement and Their Changes With Age. *ACTA PSYCHOLOGICA*, 30:3-15, 1969.
118. Welford, A. T., and J. E. Birren: *Behavior, Aging and the Nervous System*, Springfield, Illinois, Charles C. Thomas, 1965, 637 pp.
119. Welsh, K. W., J. A. Vaughan, and P. G. Rasmussen: Survey of Cockpit Visual Problems of Senior Pilots. FAA Office of Aviation Medicine Report No. 77-2, 1977.
120. Wetherick, N. E.: A Comparison of the Problem-Solving Ability of Young, Middle-Aged and Old Subjects. *GERONTOLOGIA*, 9:164-178, 1964.
121. Wetherick, N. E.: Age and Short-Term Memory Capacity for Familiar and Unfamiliar Material. *GERONTOLOGIA*, 14:204-209, 1968.
122. Zubek, J. B., and C. M. Friend: The Effect of Age on Critical Thinking Ability. *JOURNAL OF GERONTOLOGY*, 13:410-415, 1958.

NOTICE

This document is disseminated under the sponsorship of the Department of Transportation in the interest of information exchange. The United States Government assumes no liability for its contents or use thereof.