Civil Aeromedical Institute
Oklahoma City, Oklahoma

Pilot age and performance: An annotated bibliography (1990-1999)

David J. Schroeder
Howard C. Harris, Jr.
Dana Broach
Civil Aeromedical Institute
Federal Aviation Administration
Oklahoma City, OK 73125

Foreword

Most of the abstracts that comprise the annotated bibliography were extracted from the PsychINFO/PsychLIT database. Approval for their use was obtained from the American Psychological Association. References from the journal *Aviation, Space, and Environmental Medicine* were used, with approval from the Aerospace Medical Association. Abstracts from selected references were individually prepared by one of the authors.

1. INTRODUCTION

The requirement for persons involved in air carrier flight operations to no longer serve as a pilot upon reaching their 60th birthday, commonly referred to as the Age 60 Rule, was implemented by the Federal Aviation Administration (FAA) in 1959. However, those otherwise qualified pilots over the age of 60 are allowed to serve as flight engineers. A series of articles in *The Airline Pilot* magazine in 1959 (ALPA 1959a,b and Orlady 1959) provide some insight to issues and events associated with the decision to implement the Age 60 Rule. Holbrook (1974) provides additional context for the Age 60 Rule in a chapter in his book. Prominent factors included the involvement of a 59-year-old pilot in the crash of a new-model aircraft, difficulties older pilots had encountered in transitioning to turbo-jet aircraft, the predicted increase in the number and percentage of older pilots, and the increased incidence of heart disease among individuals in the older age groups. The primary concerns (Orlady 1959) were related to pilot incapacitation. However, the Airline Pilot's Association's (ALPA) (1959a,b) and Orlady's (1959) discussion of the issues involved in the draft proposal also reveal that there was a performance concern. Reference was made to age-related changes in the ability of a pilot rapidly to perform highly skilled tasks, resist fatigue, adapt to new and changing environmental conditions, and apply experience and judgement in emergency situations. Those authors also provided many of the same arguments against the proposed Age 60 Rule that have been argued in opposition to the rule in recent years. At that time, regulators were concerned with both the effects of sudden incapacitation and the more subtle consequences of age that influence everyday performance. Thus, despite implementation of the rule, efforts were underway in the summer of 1959 to initiate a research program (the FAA Georgetown Clinical Research Institute) that would result in the development of a "Physiological Aging Rating Schedule" (Holbrook, 1974, p 223).

In 1979, Congress enacted P. L. 96-171, an Act that required further study of the age-related mandatory requirement for certain pilots and first officers to be removed from air carrier flight operations. In support of this effort, the National Institute on Aging awarded a contract to the Institute of Medicine (IOM) to determine the status of scientific knowledge on medical and behavioral aspects of aging as they relate to pilot performance. Results of that review were to be used to make a recommendation regarding the Age 60 Rule. A blue ribbon panel, established in 1980 to conduct the necessary research, recommended that the age limit be maintained; however, the panel indicated that no special medical significance could be attached to age 60 as a mandatory retirement age. Additionally, the panel was unable to identify a specific test or set of tests that could be used to distinguish pilots who would pose a threat to safety because of either their performance or medical condition. A recommendation was made that the FAA, or other federal agency, initiate a study to collect the necessary medical and performance data with consideration for relaxation of the rule.

In response to this recommendation, the FAA issued an Advanced Notice of Proposed Rule Making (ANPRM) in 1982 seeking comments on a plan that would allow air carrier pilots to voluntarily enter a program for collection of medical and performance data that might permit relaxation of the rule. On the basis of the conclusion that there were no valid selective tests, there was no sufficient reason for collecting performance data on airline pilots over age 60 under conditions of actual operational stress and fatigue that do not introduce an unacceptable safety risk. The proposal was subsequently withdrawn.

Considerable controversy has surrounded the Age 60 Rule since its inception, with a number of legal actions, including the rule (e.g. Airline Pilots Association, International v. Quesada, 276 F.2d 892 [2nd Cir. 1960] cert. denied 366 U.S. 962 [1961]; Baker v. Federal Aviation Administration, 917 F.2d 318 [7th Cir. 1990]; United Airlines, Inc. v. McMann [434 U.S. 192]; Trans World Airlines, Inc. v. Thurston et al. [469 U.S. 111]; Western Air Lines, Inc. v. Criswell et al. [472 U.S. 400]; and Aman v. Federal Aviation Administration 856 F.2d 946 [7th Cir. 1988]). It is notable that the Court of Appeals in (*EEOC v. The Boeing Company* 843 F.2d 1213 [9th Cir. 1988]) ruled that the FAA Age 60 Rule could not be used by the Boeing Company as a bona fide occupational qualification (BFOQ) for pilots. The most recent court decision regarding the Age 60 rule for air carrier pilots was issued in 1998 when the United States Supreme Court refused to hear the appeal of the Professional Pilots Federation following an adverse decision of the U.S. District of Columbia Court of Appeals (Professional Pilots Federation v. FAA, 118 F.3d 758 [D.C. Cir. 1997] cert.denied 118 S. Ct. 1794 [1998]). See GAO (1998) for a more extensive discussion of the history of litigation associated with the Age 60 Rule and requests for exemptions from the rule.

During the last two decades, several studies have been carried out to assess the relationship between age, experience, and pilot performance, as determined by the occurrence of a general aviation (GA) accident (Bruckart, 1992; Golaszewski, 1983; OTA, 1990; Golaszewski, 1991, 1993; Guide & Gibson, 1991; Kay, Hillman, Hyland, Voros, Harris, & Deimler, 1994; Li & Baker, 1994; Mortimer, 1991, & Rebok, Grabowski, Baker, Lamb, Willoughby, & Li, 1999). The work of Golaszewski (1983) is most commonly cited. He found that older Class I and II pilots exhibited higher accident rates at all levels of total flight time between 101 and 5,000 hours. Class III pilots demonstrated a decline in accident rates until age 60 and over, when rates increased. Outcomes from that research are noted in the Office of Technology Assessment (OTA) (1990) review, along with recommendations regarding medical risk assessment. The Hilton Age 60 Study (Kay, Hillman, Hyland, Voros, Harris, & Deimler, 1994), which provides the most extensive analysis of pilot age and accidents, resulted in the conclusion that accident rates remained relatively constant from 40 to 60 years of age for a group of GA pilots with a Class III medical certificate and a prescribed level of overall and recent flight experience. In addition, Kay et al., 1994 reported that there was a slight increase in accident rates for those pilots around age 63. At the completion of the Kay et al., 1994 study, the FAA held a public meeting and requested comments on issues surrounding the Age 60 Rule. Information concerning the Age 60 Rule and comments associated with this meeting can be found on the internet (http://www.connix.com/~markh/age60.html). At the conclusion of the meeting and the comment period, the FAA decided to maintain the rule because the current level of safety could not be assured if this rule was relaxed. Thus, no change in the Age 60 Rule was proposed. However, in a separate regulatory action issued on December 20, 1995, the Age 60 Rule was extended, effective December 21, 1999, to cover pilots who had formerly been employed under the commuter requirements of part 135, but as a result of the Commuter Rule were obliged to serve under 14 CFR part 121.

Bennett (1990) presented a report from a sub-group on medical certification established by The European Civil Aviation Conference on Flight Crew Licensing, recommending that the age limit of 60 continue to be applied to single-pilot commercial operations and that the age limit should be set at 65 for multi-crew operations. However, for multi-crew operations it was recommended that only one of the two pilots in each crew could be age 60 or over. In addition, the sub-group indicated that formal medical risk assessments should be required at age 60 and that consideration should be given to competence testing of pilots over age 60. The report includes a discussion of the issues surrounding this decision. Simons et al. (1996) also reviewed the medical and accident data relative to the proposal to raise the maximum age limit to 65. They concluded that the move would not create additional risks, provided that medical examinations are properly conducted. Pilot age limitations for members of the European Joint Aviation Authority (JAA), are contained in JAR-FCL 3.060 (1997). The shift in policy allows pilots of ages 60-64 to operate in multi-pilot crews in Europe, provided only one pilot in that crew is age 60 or over. It further states that the holder of a pilot's license who has attained age 65 shall not act as a pilot of an aircraft engaged in commercial air transport. Member countries could adopt these policies in July 1999 provided their national laws had been revised and a standardized visit by JAA personnel had been conducted. As of December 1999, the United Kingdom, Denmark, The Netherlands, and Iceland have gained approval for operating under the new regulations. The Czech Republic has increased the upper age limit to 62. France has indicated that they will not extend the maximum age of their pilots.

The decision of the JAA, along with the continuing controversy surrounding the Age 60 Rule led the U.S. Senate, as part of the 1999 appropriation for the FAA's Research, Engineering and Development program, to direct the FAA to conduct another study of age and accidents in non-scheduled commercial (and non-commercial, if available) pilots. In response, the FAA identified difficulties associated with conducting the study as outlined, and proposed that a set of 4 studies be initiated. The final appropriation bill for FY-2000 requires the FAA to deliver data from the proposed studies to Congress.

One component of that proposal was for an updated review of the scientific literature to identify any relevant information since completion of the Hilton Age 60 Study in 1993. This report comprises that literature review.

2.0 OBJECTIVE

This report focuses on the development of an annotated bibliography of age-related studies of pilot performance. The time span for the literature search is from 1990 through 1999, and provides about a year of overlap with information contained in the bibliography generated as part of the Hilton Age 60 Study that was initiated in 1990 (Hyland, Kay, Deimler, & Gurman (1994). While the primary emphasis is on literature associated with age and pilot performance, selected documents from the broader aging literature are included to summarize the general effects of age and experience on job performance. Initial literature searches of the primary medical, aviation, and psychological data bases were conducted to identify the relevant articles. A review of the references contained in those studies identified additional articles that were considered for inclusion. We have elected not to include in the reference pool information on aging associated with automobile performance and accidents although there is clear evidence that accident rates increase for drivers age 65 and older (e.g. Massie, Campbell, and Williams, 1995). That decision was made because it is impossible to determine the extent to which driver health and the use of a variety of medications affect accident rates. In contrast, pilots are required to pass periodic physical examinations to obtain their medical certificates. They are also not allowed to use medications that are likely to influence their alertness, cognition, or coordination. In contrast, automobile drivers are allowed to drive with a variety of mental and physical conditions that would be disqualifying for pilots. However, the relationship of automobile accidents to aging is an established way of presenting data in that segment of the transportation system and has a place in the context of assessing transportation safety.

Five basic categories were established to summarize the publications and presentations related to age and pilot performance in the 1990's: reviews and comments, physiology, cognitive skills, simulator performance, and accident analysis. While there is inevitably some overlap in their content, these articles were placed on the basis of what appeared to be the dominant theme of the article. Table 1 provides the list of articles and how they were categorized. We have sought to summarize previous findings and integrate information from this recent research.

3.0 OVERVIEW OF RESEARCH OUTCOMES

3.1 Reviews and Comments

This category is perhaps the most varied since it includes articles that range from systematic reviews of the scientific literature to presentations that primarily review the history of the Age 60 Rule and provide recommendations for its revision. They include OTA's (1990) review of relevant information, a review of the literature related to pilot incapacitation (Bennett, 1992), and Hardy and Parasuraman's (1997) review, among others of the scientific literature regarding pilot age and performance actually included a majority of the articles contained in this annotated bibliography.

3.1.1 Pilot incapacitation.

Although sudden incapacitation has received limited scientific attention, its implications are often cited in discussions of the Age 60 Rule. Bennett (1992) indicated that, while nearly a third of air carrier pilots had experienced a level of physical discomfort sufficient to require another crew member to assume their duties, only about three percent were judged to pose an actual threat to safety. At the time of publication, Bennett (1992) reported that, over a 20 year period only 3 accidents in air carrier operations included medically-related causal factors. One involved severe coronary artery disease on the part of the captain, a second involved the crash of a cargo flight that was attributed in part to alcohol consumption, and the third involved a captain with a known psychiatric condition who flew his aircraft into the waters of Tokyo Bay in 1982.

Several of the important studies related to incapacitation were completed prior to 1990. For example, Chapman (1984), gathered older data (1965-1981) from 40 International Air Transport Association carriers regarding the frequency of in-flight incapacitations. During the 17-year time span of the study, a total of 277 incidents was reported for a group of 540,816 pilots. While detailed information regarding the number of accidents associated with these incidents was not provided, the author indicates that there was no accident during the17 years for which the primary cause was cardiac incapacitation. Using 1 accident in every 400 incapacitations as the basis for a risk assessment, Chapman (1984) indicated that an accident would occur every 8,307,082,800 flying hours (approximately 10^{-10}). According to Chapman (1984), this derived value is better than the risk associated with the airworthiness of components of the aircraft. Moreover, there are several assumptions associated with his calculation that suggest that the estimate may be conservative.

In referencing National Transportation Safety Board (NTSB) data, the OTA (1990) reported that no certified route air carrier accident during 1968-77 was due to acute incapacitation of the pilot. In general aviation, 1.3 percent of the 1965-75 accidents were attributed to pilot impairment or incapacitation (OTA, 1990). A sizeable percentage (60%) was associated with alcohol. In reviewing the NTSB data from 1975 through 1982, Booze (1989) reported that approximately 3 in 1,000 (.3%) general aviation accidents were attributable to some forms of incapacitation. In a case by case review of sudden in-flight incapacitation in Air France pilots and engineers, Martin-Saint-Laurent, Lavernhe, Casano, and Simkoff (1990) reported that none of the 10 incidents resulted in an accident. Of the 10 incidents, 70% occurred during cruise. The incidents associated with gastrointestinal or neurological disorders were reportedly more serious than those with a cardiovascular genesis. While older data revealed that medical disqualifications associated with coronary artery disease increased with age, a majority (58%) of the incapacitation incidents in air carriers were associated with gastrointestinal problems (James & Green, 1991).

In discussing pilot sudden incapacitation, Froom (1994) indicated that there is no current definition of "acceptable risk," although some analysts support the one- percent rule (a single incapacitation case during the course of a year – 864,000 hours). Further, the risk of an accident being caused by human error is much higher than the risk of incapacitation. The reports by Bennett (1990, 1992) and Simmons et al. (1996) suggest that the European medical community was in general agreement that, given existing medical certification procedures, the overall safety target could be maintained even if the age limit were increased to 65. Along these lines, Chapman (1984) described the outcomes of recurrent simulator training where subtle incapacitation of the handling pilot is depicted during a critical stage of flight. Occasionally, the incapacitation coincided with other failures. Of 500 exercises there were 15 occasions during which a hazard to the aircraft was present, with eight (1.6%) resulting in a crash. In a second series where the subtle incapacitation occurred in isolation during a critical stage of flight, a hazard to flight was identified in only ten out of 800 cases (1.2%). Of those ten, only 2 involved crashes (0.25% of the 800 cases). The incapacitation data appear to support two conclusions: first, incapacitations do not pose a significant risk, given present medical certification guidelines; second, incapacitations may not pose a significant increase in risks (Bennett, 1990, 1992), even if age is extended to 65.

3.1.2 Pilot Age and Performance

Tsang (1992); Hyland, Kay, Gurman, and Deimler (1994); Morrow and Leirer (1997); and Hardy and Parasuraman (1997) all provided overviews of the scientific data associated with aging and pilot performance. Hardy and Parasuraman (1997) authored the most extensive review of the effects of age on cognitive efficiency and pilot performance. Notably, Hardy and Parasuraman (1997) concluded that pilot experience does not appear to alter the typical age-related decline found in many cognitive skills. One possible exception is the area of time-sharing, where Tsang and Voss (1996), Tsang (1997), Tsang and Shanner (1998), and Tsang (1999) reported that pilots exhibit less of an age-related decline on certain time-sharing tasks than do non-pilots. A key issue concerns whether the identified age-related changes in various cognitive skills are reflective of changes in pilot performance (simulator or in flight). Hardy and Parasuraman (1997) pointed out that there was only weak evidence that age-related differences in cognition influence pilot performance. Additional discussion of these issues, along with information regarding the author's model of cognition and flight performance, will be addressed in Section 3.3.

3.1.3 Alternatives to Chronological Age

Several authors (Birren & Fisher, 1995; Glazer, 1992; Mohler, 1992; Odenheimer, 1999; Salive, 1994; Stoklosa, 1992; Stuck, van Gorp, Josephson, Morgenstern, & Beck, 1992; Williams, 1991; and Williams & Williams, 1991) have opinioned that alternative procedures and tests could be used to assess pilot capabilities rather than relying on chronological age. These opinions have been expressed by a number of individuals from the time when the Age 60 Rule was implemented. In fact, McFarland (1953) in his discussion of age and efficiency in airmen indicated that "the important variable to consider is not chronological but rather functional age or the ability to perform required duties efficiently and safely" (pg. 390). While falling short of making a specific recommendation, Williams & Williams (1991), in their review of the literature and of court decisions associated with mandatory pilot retirement, concluded that some airline pilots are capable of flying safely beyond age 60. However, there is limited scientific evidence of the extent to which the results from traditional cognitive test batteries can be used to predict pilot performance (Hardy & Parasuraman, 1997), or of the adequacy of medical tests to predict performance and identify the risk of sudden incapacitation (Stuck, et al. 1992). This is especially true when the subtle changes associated with cognitive aging are considered.

In the area of public safety, an extensive review of job requirements for police and firemen by Landy (1992), provided scientific evidence that the increased risk for sudden incapacitation with age in those occupations was not likely to significantly impact public safety. These outcomes appear to be generally consistent with the information available regarding pilot incapacitation (Bennett, 1990,1992; Chapman, 1984; Froom, et al. 1988; and Froom, 1994).

The review of the literature conducted by Landy (1992) suggested that there is considerable overlap in performance on cognitive, psychomotor, and physical tests of individuals in different age groups. Increased age also tended to increase the variability in test performance within a particular age group. Thus, there are older individuals who are capable of performing on the cognitive, psychological, and physical tests as well, if not better, than the younger people they work with. Landy (1992) indicated that there are suitable alternatives to using chronological age as a basis for retirement decisions. However, the transition to alternative procedures will require extensive testing and validation to ensure that the measures are valid and that they reliably predict job performance. The process will include the establishment of criterion-referenced cut scores for retirement decisions, including cut scores that result in acceptable false positive and false negative rates.

The establishment of a "cut score" on the basis of a criterion-related validation strategy in aviation would require that acceptable performance of a pilot be defined and measured. To accomplish these goals requires a better understanding of how aging influences different aspects of flight performance in multi-crew aircraft. Additionally, information is needed regarding the interaction between age, workload, and domain relevant knowledge as they are important considerations in Hardy and Parasuraman's (1997) model of pilot performance. Research in these areas is necessary to help scientists develop scenarios or tests that will provide measures that can be used to determine whether a pilot possesses the capability to operate an aircraft at an acceptable level of performance. Such measures would have to ensure that safety is maintained at present levels.

3.2 Physiology.

While there are numerous physiological changes that accompany aging, many that exert some influence on performance are considered under the perceptual-motor skills area. The existing sleep literature provides ample documentation of changes in sleep architecture associated with age, from infancy to older adulthood. Gander, DeNguyen, Rosekind, and Connell (1993) provided information concerning the interaction between age and sleep loss for pilots involved in long-haul operations, across four age groups from 20-30 years of age to 50-60 years of age. Amount of sleep loss generally increased with age. These findings have important implications for the establishment of duty schedules and the development of fatigue countermeasures in aviation. Changes in operator alertness associated with fatigue are a significant problem across all modes of transportation (U. S. Department of Transportation, 1999). The Department of Transportation has initiated a coordinated ONEDOT program to reduce fatigue-related concerns in all modes of commerical transportation.

3.3 Cognitive Skills.

Hardy and Parasuraman (1997) provided the most extensive review of age-related studies on pilot age and cognitive skills to date. Their findings are consistent with those of Tsang (1992) and Morrow and Leirer (1997). Age-related declines in performance were most evident in perceptual-motor and memory tasks. Lesser effects were noted in attention and problem solving/decision-making. There was little evidence, except for time-sharing tasks, that pilot expertise reduced the age-related declines in performance. Where appropriate, additional findings have been incorporated in this review. Hardy and Parasuraman (1997) described the effects of age on pilot cognition under four categories: perceptual-motor skills, memory, attention, and problem solving/decision making. An area not addressed involves general changes in physiology that can influence performance.

3.3.1 Perceptual Motor Skills.

Pilots experience many of the same general declines in perception (visual and auditory) that are found in non-pilots. In a review of perceptual and motor functions (IOM, 1981), information is provided regarding the manner in which age-related changes influence the ability of pilots to respond to glare and to rapid changes in illumination, to detect fine details under lowered levels of illumination, and to detect moving targets. Documented changes in accommodation associated with age are often reported, although bifocal lenses serve to reduce the potential effects on visual performance. In their overview of the perceptual-motor skills area Hardy and Parasuraman (1997) report that age-related changes in perceptual-motor skills are evident for a variety of pilot types. The findings appear to be stronger for GA pilots than for commercial or other (e. g. military) pilot groups. Differences between groups may be attributed in part, to the more restricted age range for military and commercial pilots.

The IOM (1981) review included a brief discussion on the age-related change in the ability to hear high frequency sounds (presbycusis). The hearing of pilots is also compromised by exposure to the noise in the aircraft environment, particularly the noise associated with piston-engine aircraft. In a recent study for example, Beringer, Harris, and Joseph (1998) demonstrated that there were significant age-related hearing losses in general aviation pilots compared with non-pilots. Specifically, older pilots displayed a greater loss in the 2 to 6kHz range. However, above age 60, the amount of hearing loss of pilots and non-pilots was at a level where the differences between these two groups were not significant. Hearing loss appears to be particularly noticeable in the frequency range of a number of alarms within GA aircraft and older pilots in a simulator study were observed to have not heard an autopilot/autotrim alarm (Beringer & Harris, 1997). However, there are no recent data to determine the extent to which similar changes occur in commercial pilots.

3.3.2 Memory.

Studies of pilot performance on memory tasks reveal significant age-related changes for most working memory tasks. Morrow, et al. (1992) found that pilots and non-pilots exhibited similar age-related declines in the recall of aviation-related materials. In a second study (Morrow, et al. 1994), had pilots readback routine Air Traffic control (ATC) communications. While expertise eliminated age differences for repeating heading commands presented visually, it reduced but did not eliminate differences from spoken messages. Age related declines were equivalent for the two groups on less domain-relevant tasks.

However, in a more recent study (Morrow, Menard, & Stine-Morrow, 1999a), the effects of expertise were not apparent in the recall of ATC messages of a route through a particular airspace. Differences with earlier studies were attributed to the fact that the task in the more recent study may have been less domain-relevant. Using the same task, but allowing pilots and non-pilots to make notes of the communications, Morrow, Menard, and Stine-Morrow (1999b) found that age-related declines in readback accuracy were eliminated by expertise. Their earlier findings, when subjects were not allowed to write down the communications were attributed to age-related declines in storage capacity.

3.3.3 Attention.

Results of age-related studies on attention are mixed. Recent emphasis has focused on assessing the effects of age on performance while an individual is required to work at 2 tasks simultaneously. For instance, Tsang (1997a), Tsang and Shanner (1995), and Tsang and Voss (1996) demonstrated age-related declines in time-sharing performance across a number of tasks. A comparison of the performance of pilots with non-pilots produced some evidence that pilot expertise associated with the multiple demands in the cockpit moderated the influence of age to some degree. In a recent study, Tsang (1999) compared the performance of pilots (n=7) and non-pilots (n=7) on various time-sharing tasks on two occasions, approximately two years apart. Outcomes reveal that both older pilots and non-pilots retained their time-sharing skill as well as younger participants. Although the sample size was small, this outcome suggests that time-sharing skills can be transferred across time and occasions..

Until recently, there were few good laboratory analogues to assess monitoring efficiency on an automated task. Parasuraman and his colleagues developed a modification of the Multi-Attribute Task Battery (MAT), involving time shared performance that can be used to evaluate a simulated automation system (Parasuraman, Mouloua, & Molloy, 1994). Using non-pilots who performed on the modified MAT, age-group differences favoring younger subjects were evident when task demands were high (Vincenzi & Mouloua, 1999). However, in a recent presentation (Hardy, et al 1999), differences in performance between younger and older subjects were not significant. Parasuraman et al. (1994) indicated that pilots showed a similar, though not as severe, decline in the detection of faulty readings when transitioning from a manual monitoring condition to an automated monitoring condition. Given the prevalence of automation in the air carrier flight deck and its likely increase in the coming years, additional research is needed to determine the potential influence of age on monitoring skills.

3.3.4 Problem solving-decision making. Evidence concerning the influence of age on problem solving-and decision making is limited and reveals mixed outcomes. Hardy and Parasuraman (1997) indicated that most of the tasks utilized in the studies are fairly simple and artificial.

3.3.5 Cognitive skills and pilot performance. As Hardy and Parasuraman (1997) noted, there are few studies that have assessed age-related differences in cognitive skills of commercial pilots. The studies that did involve commercial pilots typically compared a relatively small sample of pilots. A recent study by Kay (1995), that was not captured in the review by Hardy and Parasuraman (1997), involved the development and validation of a computerized cognitive-screening test battery for the FAA that utilized a sizeable sample of commercial pilots. CogScreen-AE incorporates 11 sub-tests: Backward Digit Span, Math, Visual Sequence Comparison, Symbol Digit Coding, Matching to Sample, Manikin, Divided Attention, Auditory Sequence Comparison, Pathfinder, Shifting Attention, and Dual Task. Performance measures include response speed, response accuracy, and response throughput.

Nearly 600 commercial pilots were administered CogScreen-AE to develop the normative database. Efforts were made to include equal numbers of pilots in each of 6 age groups from under 35 years to over 54 years of age. Kay (1995) reported that while there were significant correlations between age and performance on various measures, age accounted for 9% or more of the variance on only 5 measures. These measures were derived from the Symbol Digit Coding, Visual Sequence Comparison, Dual Task, and Shifting Attention subtests. Thus, there was evidence of age-related changes in cognitive skills among commercial pilots. Significant differences were noted for both individual and time-shared tasks.

Hardy, Slick, Satz, D’Elia, Uchiyam, and van Gorp (1998) also evaluated the relationship between age and cognitive test scores in a group of 228 licensed professional pilots. The pilots all held Class II Medical Certificates and ranged in age from 28 to 62. A battery of six neuropsychological tests was administered (Trail Making, Stroop Color Word, the Grooved Pegboard, the Symbol Digit Modalities, the Rey Auditory Verbal Learning, and the Rey-Osterith Complex Figure). Each test score was regressed on pilot age. Despite significant slopes for measures from five of the tests, the amount of variance explained by age was relatively low, between one and nine percent. The authors also reported that there was considerable overlap of the test scores across age. Age-related declines in performance were evident on speeded tests involving attention and concentration, inhibition, basic psychomotor skills, and delayed verbal and visual recall. It has been suggested (OTA, 1990) that subtle changes in cognitive functioning associated with aging may be sufficient to override the benefits of experience and result in higher accident rates in older pilots. Nevertheless, the overall conclusion concerning the relationship between age and cognitive abilities in pilots is that pilot expertise does not appear to influence the typical age-related declines in cognitive abilities evident in non-pilots. The possible exception could involve performance on computer tests involving time-sharing, where pilots evidenced smaller age-related declines in performance than non-pilots.

3.4 Simulator Performance.

Much of the research on pilot age and simulator performance has been conducted at the Stanford University Laboratory of Dr. Jerome Yesavage. Leirer, Yesavage, and Morrow (1989) had reported that the performance of older pilots compared to that of younger pilots, exhibited greater deviation from a prescribed flight path. Older pilots also exhibited greater impairment in simulator performance following alcohol consumption. However, follow-on studies did not support the age differences in overall flight performance found in this initial study (Morrow, Leirer, & Yesavage, 1990; Morrow, Yesavage, Leirer, Tinklenberg (1993), Morrow, Yesavage et al. (1993); Taylor, Dohlert, Morrow, Friedman, & Yesavage (1994); and Yesavage, Dohlert, and Taylor (1994). Differences in outcomes could not be clearly attributed to the age categories used since several of the more recent studies involved a greater age difference. Variability in the effects of age on performance and the small number of subjects (N=7) in the 1989 study may have been significant factors. However, there were other conditions under which age-related differences in performance were found, including handling malfunctions and responding to ATC communications (Morrow, Leirer, & Yesavage, 1990; Morrow, Yesavage, Leirer, & Tinklenberg 1993; Morrow, Yesavage, Leirer, Dolhart, Taylor & Tinklenberg 1993; Taylor, et al., 1994a; and Taylor, et al. 1994b.

Hyland (1993) and Hyland, Kay, and Deimler (1994), as part of the Hilton Age 60 Study, assessed age-related differences in pilot performance on specialized flight scenarios in a Boeing 727 simulator. Performance of 40 pilots under each of three workload conditions (routine, moderate, and high/emergency) was assessed using flight-path deviations and subjective assessments of performance. While significant age effects were evident in the subjective ratings, no significant differences were found in the flight-path deviations. Furthermore, the authors were unable to determine whether the different outcomes in the two performance measures were attributable to the lack of sensitivity of the flight-path deviation measures or to a subjective-rating bias.

The most recent studies to evaluate the relationship between age and pilot simulator performance (Yesavage et al. 1999; Taylor, O'Hara, Mumenthaler, & Yesavage, in press) come from an ongoing longitudinal study of pilot age and performance that was funded by the National Institute of Aging. In this study, Yesavage and his colleagues are investigating the effects of age-related changes in performance across 3 years using a sample of 100 pilots between the ages of 50 and 69. Their initial study (Yesavage et al. 1999) revealed that pilot performance on several flight tasks declined significantly with age. Using a flight summary score, older pilots evidence poorer performance (r= -.35). A regression analysis revealed that a curvilinear model explained 18% of the variance compared to 14% for the linear model. In reviewing the component scores of pilot performance the authors noted several significant correlations between age and performance for Traffic Avoidance and Approach. Regression analyses revealed that linear or curvilinear models accounted for 7% to 22% of the variance. Repeated assessment at 1-year intervals will allow the authors to determine how performance changes across time. These outcomes challenge Hardy and Parasuraman's (1997) conclusion that primary flight performance does not differ significantly between younger and older pilots. Subsequent assessments of performance in this group will provide a clearer understanding of how pilot aging influences flight performance.

For this same group, Taylor et al. (in press) investigated the relationship between performance on the CogScreen-AE test battery and flight-simulator performance. A factor analysis of the CogScreen-AE scores was used to generate five composite scores (Speed/Working Memory, Visual Associative Memory, Motor Coordination, Tracking and Attribute Identification). Of these scores, Speed/Working Memory had the highest correlation with the flight performance summary scores. Overall, four of the factors were found to explain 45% of the variance in simulator performance. Furthermore, age contributed a significant amount of variance (6%) to the prediction of simulator performance over and above the cognitive variables. Thus, there are cognitive performance test batteries that can predict age-related changes in pilot performance. Further evidence of the link between certain of the CogScreen measures and flight performance is provided by Hoffman, Hoffman, and Kay (1998). In a study of 115 first officers of a major airline, CogScreen variables, past flight experience, agreeableness, aviation knowledge, and intelligence tests were predictive of crew resource management (CRM) performance gathered by an in-flight observation instrument. The authors comment that the most important factors from CogScreen were those involving multi-tasking. Although there may be a question of the degree to which age modifies performance on time-shared tasks. (Tsang 1992, Tsang and Shaner, 1998 versus Kay 1995) certain of those tasks may be among the cognitive tests that best predict pilot performance.

Pelegrib, Maho, and Amalberti (1995) provided information regarding age and training success of pilots transitioning to the Airbus A320. Compared with a failure rate of 2 to 5% in 29-44 year old pilots, the rate increased to around 8% for 45-48 year old pilots and was around 16% for those 49 and older. There was evidence that pilots who had a greater number of total flight hours in the current aircraft type had greater difficulty making the transition. The authors indicate that efforts have been made to devise improved instructional methods to assist older pilots. While the study of Pelegrib and associates is not necessarily a study of pilot performance in the simulator, a significant portion of pilot training involves the simulator. Morrow (1996) discusses the importance of age-related changes in cognitive abilities of pilots for the design of new communication procedures and technologies.

3.5 Actual Flight Performance.

As pointed out earlier, Hardy and Parasuraman (1997) have reviewed nearly all of the studies of actual flight performance that are included in the annotated bibliography section of this report. They base their conclusions regarding age effects on performance primarily on the extensive investigation that occurred as a part of the Hilton Age 60 Study (Kay et al. 1994). Kay and associates were critical of a number of the earlier studies, both on methodological grounds and because the conclusions were not based on statistical analyses (notably Golaszewski, 1983; Guide and Gibbon, 1991; Mortimer, 1991; and OTA, 1990). Kay et al. (1994) found that accident rates of older pilots with a Class III medical certificate and an amount of total flight hours and recent flight hours that exceeded a specified amount (500 and 50 respectively) evidenced a gradual decline in accidents from age 40 through the early 60s, with a slight increase in the 65-69 age group. Pilots with a Class II medical certificate evidenced a similar pattern. The increase in accident rates for GA pilots around age 63 found by Kay et al. (1994) is interesting in light of the available information from automobile accidents. For example, Massie, Campbell, and Williams (1995), using data from a 1990 National Personal Transportation Survey, the 1990 Fatal Accident Reporting System, and the 1990 General Estimates System, determined mileage-based rates for automobile accidents involving injuries and fatalities. Comparisons across age groups per 100-million miles for fatal accidents revealed that rates declined from 16-19 year olds to the 30-34 year old age group. The incidence remained relatively stable through the 60-64 year old age group after which rates increased substantially.

Golaszewski (1991) used a more recent set of data (1983 to 1988) and additional breakdown of pilot groups to assess age and accident rates. He subsequently incorporated statistical analyses and redefined the GA pilot group to evaluate the effects of age and experience (Golaszewski 1993). His findings, pertain to 3 separate groups of pilots: a) professional pilots with a Class I medical certificate; b) professional pilots with a Class II medical certificate and flight instructors with a Class I or Class II medical certificate; and c) other general aviation pilots including those with Class I, II, or III medical certificates. Pilots who reported an occupation as an airline pilot, navigator, or flight engineer were not included in the study. Accident rates for Group A declined through age 40-49 then increased though age 60-69. Rates for Group B increased from age 20-29 through the oldest age group. Pilots in Group C showed relatively stable steady accident rates from 20-29 through 60-69. Golaszewski (1993) also looked at a modified Group C by extracting pilots with a Class I or Class II medical certificate who either did not report an occupation or reported a non-aeronautical occupation. That group demonstrated a somewhat different pattern of age-related change in accidents than Groups A and B. Accident rates declined steadily from the 20-29 year old age group though the 60-69 year old age group. It seems logical that differences in the outcomes from the Kay et al. (1994) and Golaszewski (1993) studies can be attributed to the selection criteria associated with establishing the various pilot groups and in the calculation of the exposure hours for the various groups. Li (1994) comments on the general methodological issues associated with studies of age and accident rates in pilots as well as specific comments concerning how Golaszewski (1983) determined the numerator and denominator for his study. Additional analyses are needed to clarify the factors associated with the differences in outcomes.

Using a case-control methodology, Lubner, Markowitz, and Isherwood (1991) determined the accident risk between a group of “accident pilots” and controls selected from the FAA’s Airmen Registry database. They identified the manner in which risk of accidents and violations were influenced by age, gender, medical certification, airmen certification, and FAA region. A direct measure of flight time was not included in the analysis. Older pilots were defined as those who were born before 1950, the median age of this study. Younger pilots were born after 1950. Older pilots were at less risk than younger pilots for both accidents and violations.

McFadden (1997) used logistic analyses to determine the comparability of pilot-error accidents for male and female US Airline Pilots. Controlling for age, experience and other factors McFadden (1997) found that male and female pilot accident rates did not differ significantly. In building the predictive model, regression analyses revealed that accident rates declined as pilot experience (total flight hours and recent flight time) and age increased. However, as is typical with many of the studies, age and experience were confounded.

Li and Baker (1994) explored the human factors and pilot demographics associated with commuter and air taxi crashes, using a case-control method. Using pilots (n = 725) involved in air taxi crashes during 1983-1988, the authors identified 1,555 pilots, who were flying Part 135 operations at the time of the medical examination. The 1,555 pilots were similar to the "accident pilots" in terms of certificate class, occupation, employer, recent flight time and total fight hours. Using logistic regression and other statistical procedures, the authors found evidence that pilots involved in commuter aircraft and air taxi crashes had a significantly higher prevalence of having had crash/incident or violation records in the previous 3 years, when compared with the control group. Li and Baker (1994) reported that the relationship between total flight time, age, and recent flight time was complex. However, when adjustments were made for total flight time and recent flight time, the risk of an accident increased with age. The authors also point out that greater experience appears to keep older pilots from being at excess risk.

The most recent study of pilot age and accidents (Rebok et al., 1999) utilized a historical analysis of a cohort of 3,592 pilots who flew air carrier and air-taxi flights and were between the ages 45 and 54 in 1987. Specifically, the crash records of these subjects from 1983 to 1997 were examined. Comparisons were made of pilots in the following age groups: 40-47, 48-55, and 56-63. Pilot performance was a factor in 58% of the older pilots' crashes compared with 71% of the younger pilots' crashes. Rebok et al. (1999) concluded that there "appear to be no significant age differences in the pilot performance factors contributing to aviation crashes" (pg. 2). It is worth noting that several of the more recent studies (Lubner, et al., 1991; Li and Baker, 1994; McFadden, 1997; and Rebok et al., 1999) have used improved study designs and statistical procedures to determine the relationships between pilot age, experience, and other factors as they relate to aviation accidents.

As evidenced in the review by Stone (1993), the military is also concerned about the impact of aging on military pilots. Problems in determining exposure data and the more limited range of ages involved in military aviation make it difficult to interpret the accident rates across age groups. Thus, Stone concludes that little is known about the influence of age on the flight performance of military aviators.

There are several issues that complicate the interpretation of the age and accident data. The major issues are described briefly below.

- Most comparisons of age and accidents are cross-sectional in nature; that is, groups of individuals within a particular age group are compared with individuals in older or younger age groups. Kay et al (1994) attempted to resolve some of these cohort differences by extracting longitudinal data for their analyses. Bruckart (1992) identified a number of changes in pilot demographics across time. Differences in the educational and life experiences of persons born at different times can impact lifestyle and perhaps performance capabilities. For example, older pilots have had less experience with computer technology, which may pose difficulties in adapting to and utilizing computer-based training and upgrading to advanced aircraft technologies that require computer skills. Differences may also be associated with the retroactive interference caused by prior learning environments. Older commercial pilots are also likely, due to seniority, to have preferential choice of routes, which may reduce exposure to takeoffs and landings per flight hour. Longitudinal studies allow the scientist to determine how performance of an individual changes across time. However, longitudinal studies are more expensive and also have problems associated with the effects of changes in procedures, equipment, and traffic density across time.

- The available databases do not contain the necessary information to identify the ideal exposure data required for the analyses. Total flight hours and recent flight hours are not separated into the type of operations involved (air carrier, commuter/air taxi, general aviation).

- Exposure data may differ from one database to another (Li, 1994). It is important that investigators clarify the procedures they used to derive the numerator and denominator in equations for determining accident rates. Additional knowledge is needed to determine precisely how various selection criteria can influence the outcomes and overall accident rates across age and other demographic variables.

- The number of accidents involved in air carrier operations is small and does not permit effective comparisons across age. Additionally, pilots operating under Part 121 are not included in the database after they reach age 60.

- If GA accidents are used, can the outcomes be generalized to operations involved in the air carrier environment? How does one identify the appropriate group of pilots for a cross-sectional study? Golaszewski (1991 and 1993) resolved this by using only those individuals who indicated that they were professional pilots, for his investigation of pilots with a Class I or Class II Medical Certificate. All pilots were included for the analysis of those with a Class III Medical Certificate. However, Golaszewski (1993) did extract a limited subset of GA pilots who held a Class III Medical Certificate for some analyses. On the other hand, Kay et al. 1994 defined their GA group by requiring a Class III medical and a certain level of total hours and recent flight hours, although they also looked at pilots holding Class I and II medical certificates.

- Should selection of the appropriate group involve medical certification class and type of pilot certificate or medical certification class and various experience parameters? Even with the use of medical certification class, type of pilot certificate, and various experience parameters, the pilot medical database does not provide any indication of the type of operation involved in obtaining the various hours of experience. For instance, Kay et al. (1994) indicated that information was needed regarding the number of takeoffs and landings a pilot completed during a specified time period.

- Another issue concerns the appropriate statistical procedures to use in analyzing the data. Golaszewski (1983) recommended that statistics are not necessary because the complete set of aviation accidents (i.e., the total population) often is used. Statistics were also not applied by OTA (1990), Guide and Gibson (1991), and Mortimer (1991). However, Kay et al. (1994) provided a rationale for the use of appropriate statistical procedures. Rebot et al. (1999) and McFadden (1997) also applied various statistical procedures. More recently Golaszewski (1993) incorporated statistical comparisons in his analyses. However, more appropriate statistical procedures may now be available for use with low-frequency or rare event data. Research by Li and Baker (1994), McFadden (1997), and Rebok, et al. (1999) have illustrated how different methodologies and statistical analyses can be used to examine accident data. Additional discussion of these and other related issues can be found in Kay et al. (1994) and Hardy and Parasuraman (1997).

3.6 Age and Expertise

An issue that is often brought up in discussions or reviews of the literature regarding the effects of age on performance concerns the benefits of experience and expertise. Researchers and the general public are typically of the opinion that experience will reduce the magnitude of the age differences in cognitive functioning. As Salthouse (1990) points out, despite the general acceptance of this concept, the scientific evidence is less clear cut. Salthouse provides a review of the literature regarding the effects of increased age on familiar and novel tasks, whether increased experience reduces the magnitude of overt manifestations of age-related differences in performance, and finally, whether age-effects are attenuated when the tasks are overlearned and in continuous use, as one would expect with respect to various occupational activities. The latter aspect is particularly pertinent with regard to age, pilot experience, and flight performance. Salthouse, in reviewing a number of studies, including those involving air traffic controllers and pilots, tentatively concluded that age-related declines in performance are still evident in measures of occupationally relevant activities. Salthouse (1994), in discussing the relationship among age, experience, cognitive processes, and occupational performance theorizes that the accumulation of occupation-specific knowledge associated with age may explain how older employees maintain job performance. The declines in cognitive performance evident in pilots and non-pilots are often attributed to the effects of age on fluid intelligence (Hardy & Parasuraman, 1997). Fluid intelligence refers to the ability of the individual to rapidly take in and process information. In contrast, crystallized intelligence, which is based on the store of information or knowledge an individual builds up through experience, is less susceptible to aging. The benefits of flight experience should be reflected by an increase in the domain-specific knowledge base.

The material previously reviewed suggests that there are some tasks for which the flight experience gained by pilots does reduce the expected age-related decline in performance. Lassiter, Morrow, Hinson, Miller, & Hambrick (1996), using a PC-based flying task, determined the effects of age on a Sternberg choice reaction time secondary task. Expertise reduced the effects of the introduction of the secondary task (increased workload) on accuracy of responses. This is consistent with the findings of Tsang and Shaner (1994), Tsang and Voss (1996), Tsang (1998), and Morrow, Leirer,Altiere, and Fitzsimmons (1994). With respect to the benefits of expertise on simulator and pilot performance, outcomes are mixed. The more recent research, involving a carefully selected group of pilots across various age groups (Yesavage, et al. 1999) indicates that expertise was not sufficient to obviate age differences in pilot performance, but this study did not involve air carrier pilots. Additional research is needed to determine more precisely the aspects of pilot performance that are influenced by the aging process. Studies of aviation accidents provide some data regarding the benefits of experience. The outcomes from Kay, et al. (1994) suggest that pilot experience and expertise allowed older pilots to maintain performance and demonstrate no increase in accident rates. Outcomes from Golaszewski (1983, 1991, 1993) where certain pilot groups demonstrated an increased incidence of accidents with increased age still showed evidence that experience and recent flight time were somewhat protective. Li and Baker (1994), in their study of commuter and air taxi crashes noted that the experience gained through additional flight time was of greatest benefit early in the life of a pilot. Morrow and Leirer (1997) described several mechanisms whereby expertise can reduce age-related declines in resources: maintenance, compensation, accommodation, expertise, and environmental support. Additional research is needed to determine the extent to which these mechanisms may be used by pilots to reduce the effects of the decline in resources associated with aging.

4.0 SUMMARY AND CONCLUSIONS

While sudden incapacitation is often cited as a major concern in efforts to remove the age restriction for air carrier pilots, data presented (Froom 1994; Froom, et al. 1988; Simmons, et al., 1996, OTA, 1990; and Bennet, 1990, 1992) concerning the frequency and extent to which incapacitation events posed a threat to flight safety suggest that incapacitation does not pose a significant risk in light of the influence of other human factors, e.g. judgment, decision making, and communication. In fact, OTA (1990) stated that even more rigorous medical examinations were not likely to significantly alter accident rates since no sudden physical impairment had been associated with an air carrier accident. This conclusion appears to be at odds with Bennet (1992) who cites an instance where severe coronary artery disease was involved in an accident. Estimates of the relatively low risk associated with sudden incapacitation appear to have been a factor in the decision by the JAA to allow European contries to adopt 65 as the upper age limit for multi-crew operations. While less concerned about sudden incapacitation, OTA (1990) was concerned about the effects of subtle age-related changes in cognitive abilities that could have a significant influence on pilot performance.

Recent research is consistent with Hardy and Parasuraman's (1997) conclusion that older pilots exhibit many of the age-related differences in cognitive abilities, when compared with their younger colleagues in the general population. The influence is observed most clearly on tasks involving memory and rapid processing of information. With the possible exception of selected time-shared tasks, flight experience does not appear to reduce the extent to which age-related declines in performance are detected. Furthermore, many of the authors reported that performance variability increased with age. The precise influence of these age-related changes in cognitive performance on performance in the simulator and in the operational flight environment is less clear.

The more recent research from the Stanford laboratory of Dr. Yesavage (Taylor et al., in press, and Yesavage et al. 1999) clearly demonstrates some documented effects of age on pilot performance in a GA simulator. Older pilots performed more poorly on several measures of pilot performance gathered during the special simulation scenarios. Taylor et al. (in press) also demonstrated that measures from a computerized neuropsychological test battery could be used to predict pilot performance. Using the same test battery, Yakimovich, Strongin, Govorushenko, Schroeder, & Kay (1994) were able to predict flight deviations of a group of Aeroflot pilots, using information gathered from flight data recorders. These findings demonstrate that there are computerized test batteries that can be used to accurately evaluate age-related changes in performance and that those tests are related to aspects of flight performance in a simulator and in flight. There is actually a large number of computerized test batteries that are available and have been used to assess the effects of alcohol, drugs, and fatigue on performance (Gilliland & Schlegel, 1997). Additional research is needed to determine the extent to which these measures of cognitive abilities predict the performance of commercial pilots under multi-crew conditions.

Evaluations of the effects of age on pilot flight performance have generally focused on the relationship of age to aircraft accidents. Since the number of air carrier accidents is small, researchers have placed more of their attention on the relationship between age and general aviation accidents as a surrogate. There are several methodological concerns associated both with the establishment of these GA databases and with the conduct of the analyses. Kay et el. (1994) have demonstrated, that for a group of general aviation pilots with a specified amount of experience, accident rates did not increase with increasing chronological age of pilots until around age 63. In contrast, Golasezwski (1991, and 1993) has demonstrated, with data from pilot accidents during 1980-1988, that accident rates for professional pilots increased steadily with age, with the exception of those professional pilots with a Class I Medical Certificate. For that group, accident rates declined from the 20s through 50s after which there was an increase in accident rates. On the other hand, the group of non-professional pilots (general aviation) included in Golasezwski's analyses (1993) evidenced a decrease in accident rate with an increase in age. It would appear then, that more extensive analyses are needed to determine the effect of the various selection parameters on these outcomes. Recent work by Rebok et al. (1999) involving air carrier and air-taxi flights suggest that age was not a significant factor in pilot performance.

While feedback from the comment period held by the FAA following completion of the Hilton Age 60 study was reported (see internet: http://www.connix.com/~markh/age60.html) as favoring maintenance of the Age 60 Rule, the vast majority of the scientists who have subsequently reviewed and commented on the issues associated with the continued use of chronological age suggest that there are better alternatives. The JAA in an effort to harmonize rules within Europe, agreed to allow air carrier pilots involved in multicrew situations to fly until they reach age 65. This, of course, merely changes the chronological age used as the criterion for conduct of flight duties. With the exception of OTA (1990) and Stuck et al. (1992), few of the authors who recommend removal of the Age 60 Rule have provided clear recommendations regarding the components of an improved screening process. Recommendations regarding the criteria and decision rules proposed to allow pilots to fly beyond age 60 are also generally not spelled out. Landy (1992), in his review of the chronological age limitation for public safety officers did provide details regarding the process required to establish the reliability and validity of tests proposed for screening of those personnel. He also indicated that a considerable investment will be required to implement the non-age-based requirements. OTA (1990) suggested that costs associated with additional medical screening procedures and with responding to legal challenges for those individuals who feel the new procedures are discriminatory will increase significantly.

A transition to a criterion-based process for determining a pilot's fitness to fly beyond Age 60 will require extensive additional research. From the medical side it will require the identification of additional medical and neuropsychological tests that will provide the necessary new information to determine if there are medical conditions that pose a significant risk for continued flying. For example, while CogScreen-AE was initially developed and validated to assess aspects of cognitive functioning that may be impacted by alcohol, drugs, or other neurological disorders, additional validation research is needed to determine the age appropriate cut score for identifying pilots who may be unfit to fly or require additional medical tests. As indicated by OTA (1990) the introduction of additional medical tests would result in a substantial increase in the cost of medical examinations for pilots.

Since the final decision to remove a pilot or first officer from his/her position is likely to be performance-based, employers will need to develop and validate the necessary assessment (simulator or flight) procedures for determining whether a pilot can operate the aircraft at an acceptable level of safety. These test scenarios will need to be sufficiently intense to demonstrate that the pilot can operate the aircraft safely under demanding operational conditions where workload is high and pilot resources and memory are challenged. Because this procedure involves a retirement decision, it will have to be sufficiently rigorous to withstand the legal challenges that inevitably will be raised regarding age discrimination. Considerable resources will be required to develop and validate these procedures and to administer them periodically to all pilots. Once challenged, this could mean that all pilots might be tested periodically and that some pilots under the age of 60 could be removed from their positions if they did not perform at an acceptable level. The economic burden on the FAA and corporations to develop a non-age safety basis for denying pilots continued employment could be significant.

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Table 1. Summary Categorization of Pilot Age and Performance Studies. Review/comments (R/C), Cognitive Performance (Cog Perf), Simulator Performance (Sim Perf), Accident Rate (Acc Rate), Physiological (Physiol).

AUTHORS	**R/C**	**COG PERF**	**SIM PERF**	**ACC RATE**	**PHYSIO**
Bennet (1990)	X				
Bennet (1992)	X				
Beringer, Harris, & Joseph (1998)					X
Birren & Fisher (1995)	X				
Bruckart (1992)				X	
Della Rocco & Schroeder (1992)	X				
Fromm (1994)	X				
Gander, DeNguyen, Rosekind, & Connell (1993)					X
Glazer (1992)	X				
Golaszewski (1991)				X	
Golaszewski (1993)				X	
Guide & Gibson (1991)				X	
Hardy & Parasuraman (1997)	X				
Hardy, Mouloua, Molloy, Dwivedi, & Parasuraman (1999)		X			
Hardy, Slick, Satz, D'Elia, Uchiyama, and Van Gorp (1998)		X			
Hilton Systems, Inc. (1994)	X				
Hyland, Kay, & Deimler (1994)			X		
Hyland, Kay, Deimler, Gurman (1994)	X				
Hyland (1993)			X		
Jones (1992)	X				
Kay, Hillman, Hyland, Voros, Harris, and Deimler (1994)				X	
Kay (1995)		X			
Landy (1992)	X				
Lassiter, Morrow, Hinson, Miller, & Hambrick (1996)		X			
Li (1994)	X				
Li, and Baker (1994)				X	
Lubner, Markowitz, & Isherwood (1991)				X	
Martin-Saint-Laurent, Lavernhe, Casano, & Simkoff (1990)					X
McFadden (1997)				X	
McKinnon (1992)	X				
Mohler (1992)	X				
Morrow (1996)	X				
Morrow & Leirer (1997)	X				
Morrow, Leirer & Altiere (1992)		X			
Morrow, Leirer, Altieri, and Fitzsimmons (1994)		X			
Morrow, Leirer, & Yesavage (1991)			X		
Morrow, Leirer, Yesavage, & Tinklenberg (1991)			X		
Morrow, Leirer, & Stine-Morrow (1999a)		X			
Morrow, Leirer, & Stine-Morrow (1999b)		X			
Morrow, Yesavage, Leirer, Dohlert, Taylor, & Tinklenberg (1993)			X		
Morrow, Yesavage, Leirer, & Tinklenberg (1993)			X		
Mortimer (1991)				X	
Odenheimer (1999)	X				

Table 1(con't.). Summary Categorization of Pilot Age and Performance Studies. Review/comments (R/C), Cognitive Performance (Cog Perf), Simulator Performance (Sim Perf), Accident Rate (Acc Rate), Physiological (Physiol).

AUTHORS	**R/C**	**COG PERF**	**SIM PERF**	**ACC RATE**	**PHYSIO**
Office of Technology Assessment (1990)	X				
Parasuraman, Mouloua, & Molloy (1994)		X			
Pelegrib, Maho, & Amalberti (1995)			X		
Rebok, Grabowski, Baker, Lamb, Willoughby, & Li (1999)				X	
Reinhart (1990)	X				
Salive (1994)	X				
Salthouse (1990)	X				
Salthouse (1994)	X				
Serwer (1990)	X				
Simmons, Valk, Krol, & Holewijn (1996)	X				
Stoklosa (1992)	X				
Stone (1993)	X				
Stuck, van Gorp, Josephson, Morgenstern, & Beck (1992)	X				
Taylor, O'Hara, Mumenthaler, & Yesavage (In Press)			X		
Taylor, Dolhert, Morrow, Friedman, & Yesavage (1994)			X		
Taylor, Yesavage, Morrow, Dohlert, Brooks, & Poon (1994)			X		
Tsang (1992)	X				
Tsang (1997a)		X			
Tsang (1997b)		X			
Tsang (1997c)	X				
Tsang (1999)		X			
Tsang & Shaner (1995)		X			
Tsang & Shaner (1998)		X			
Tsang, Shaner, & Schnopp-Wyatt (1995)		X			
Tsang & Voss (1996)		X			
Vincenzi and Mouloua (1999)		X			
Williams (1991)	X				
Williams & Williams (1991)	X				
Yakimovich, Strongin, Govorushenko, Schroeder & Kay (1994)				X	
Yesavage, Dolhert, & Taylor (1994)			X		
Yesavage, Taylor, Mumenthaler, Noda, & O'Hara (1999)			X		

BIBLIOGRAPHY
Pilot Age and Performance

This bibliography represents an update of the bibliography prepared for the Hilton Age 60 study initiated in 1990 (Hyland, D.T., Kay, E.J., Deimler, J.D., and Gurman, E.B. *Age 60 Study, Part II: Airline pilot age and performance—A review of the scientific literature*. Technical Report DOT/FAA/AM-94/21, Civil Aeromedical Institute, FAA, Oklahoma City, 1994). While the primary focus is on literature associated with pilot age and performance, selected documents are included from the broader literature that relate to job performance and age.

Bennett, G. (1990). Harmonization of age limits for professional pilots. Report of the FCL Sub-Group on Medical Certification. Presented at the European Civil Aviation Conference, Paris, France, September.
Abstract
A sub-group of the ECAC FCL Committee, consisting of a physician, a psychologist, a training captain, and a licensing expert recommended that the age limit of 60 should be applied to single-pilot commercial operations but that the age limit should be 65 for 2-pilot or multicrew operations. In this case only one of the two pilots in each crew should be aged over 60 or already flying on a medical waiver and special consideration should be given to competence testing in pilots over age 60. These recommendations, made on a basis of accident and incident experience and epidemiological studies, were accepted by the main FCL Committee subject to the agreement of the Medical Group, which is invited to endorse them. Formal medical risk assessment should be required at age 60.

Bennett, G. (1992). Medical-cause accidents in commercial aviation. *European Heart Journal*, 13(Supplement H), 13-15.
Abstract
This article is focused on a discussion of the frequency of incapacitation in flight and medical-cause accidents. A safety target of 10 million or more hours in multi-crew aircraft for each fatal accident has been established. The risk of pilot incapacitation contributing to these accidents should be less than 1 accident per 100 million hours. Research indicates that nearly 33% of pilots have experienced a level of physical discomfort that required another crew member to assume their duties. Safety is threatened in only about 3% of the situations. According to the author, the critical time period is the first three minutes or last three minutes of flight. Most of these incidents have been attributed to gastrointestinal symptoms. Flight simulator training has been used to promote pilot recognition of incapacitation and to assist crew members in developing appropriate response strategies. In the past 20 years the author identified only three incidents where medically-related causal factors were cited; a 1972 Trident aircraft that stalled on climb out at London when the captain was incapacitated due to severe coronary artery disease; a DC8 freighter that crashed in Anchorage in 1977 when the captain had a high blood alcohol level; and a DC8 that was flown into the waters of Tokyo bay in 1982 by a captain who had a known psychiatric history. Information is provided regarding the initial and recurring medical examination required of commercial pilots in European countries. The author concludes that current medical certification

practices are sufficient to ensure that the medical-cause target for aircraft accidents will be met.

Beringer, D.B., Harris, H.C., & Joseph, K.M. (1998). Hearing thresholds among pilots and non-pilots: Implications for auditory warning design. *Proceedings of the Annual Meeting of the Human Factors and Ergonomics Society*, pp. 92-96.
Abstract
Information gained from a simulator study suggested that older general aviation pilots were experiencing difficulty hearing specific auditory warnings in the cockpit. Hearing threshold data were collected for 150 non-pilots and 150 pilots. Stratified age sampling was used to develop 10 age groups (22 and younger to 63 and older). Separate ANOVAs were conducted for data from the left and right ears. As anticipated, both groups evidenced the higher frequency threshold shifts associated with aging and environmental exposure. Pilots exhibited greater threshold shifts between 2 and 6 kHz. Greater change was evident for the left ear that is frequently exposed to greater noise due to the seating arrangement, especially in twin-turbine aircraft. The second phase of the study involved a preliminary effort to validate the design and presentation of auditory warnings.

Birren, J.E., & Fisher, L.M. (1995). Rules and reason in the forced retirement of commercial airline pilots at age 60. *Ergonomics*, 38, 518-525.
Abstract
Examines the context of mandatory retirement in airline pilots. In the 35 yrs since the age 60 mandatory retirement age for commercial airline pilots was adopted by the Federal Aviation Administration, many changes have occurred in life expectancy, mortality and morbidity rates, economic conditions, and the nature of flying that impact on that decision. It is suggested that policymakers look at 3 general areas as criteria when adjusting the age of mandatory retirement: actual job performance, information processing capacity, and physical capacity. Information processing and physical capacity provides information about the necessary but not sufficient conditions that must be met to fly an aircraft. Actual job performance is the final measure of a pilot's ability to fly at any age.

Bruckart, J.E. (1992). Analysis of changes in the pilot population and general aviation accidents. *Aviation, Space, and Environmental Medicine*, 63, 75-79.
Abstract
General Aviation pilots have been involved in a steadily decreasing number of accidents over the past 20 years. Changes in the age distribution, certification, and flying habits of these pilots make direct comparison of accident statistics inaccurate. This study reviews changes in the pilot population over the past 20 years to analyze their impact on accident statistics. Pilot age and certificate distributions from 1968 to 1987 were assembled from annual FAA surveys. Information about pilots involved in accidents was collected from annual NTSB reports. Trends in pilot age distribution, certification, aircraft use, flight planning, and weather were reviewed. The accident experience from the first 5 years of the study period was used to construct an adjusted plot of expected aircraft accidents. From 1968-87, the mean pilot age increased from 35 to 40 years and the number of pilots over the age of 60 increased five-fold. The number of pilots with Air Transport Pilot

(ATP) certification tripled and Instrument certification increased 80%. Accidents where an Instrument Flight Rules (IFR) flight plan was filed increased from 3.6% to 6.6% without a corresponding increase in the number of accidents in weather at or below instrument meterologic conditions (IMC). The accident experience from 1968 to 1973 predicted 116,000 accidents from 1968 to 1987. The actual number of accidents was 40% less than predicted. The average pilot age has increased both due to more pilots over the age of 50 and less young student pilots. Despite an increase in the number of pilots holding an instrument rating and filing instrument flight plans, there was not an increase in IMC weather-related accidents. Comparison of adjust accident rates to the actual accident experience shows a marked reduction in accident rates for each pilot age group during the 20-year period. This represents a real advancement in aviation safety where improved pilot performance resulted in fewer accidents.

Della Rocco, P.S., & Schroeder, D.S. (1992). Studies on mandatory retirement age for pilots. Paper presented at the 63rd Annual Scientific Meeting of the Aerospace Medical Association, Miami Beach, FL. Abstract in *Aviation, Space, and Environmental Medicine*, Vol. 63, p. 427, 1992.
Abstract
Introduction. The "Age 60 Rule" (14 C.F.R. Part 121) has generated varying levels of controversy during its 30 year existence. Research by Golaszewski (1983) has been used to support the conclusion that pilots of age 60 and older have higher accident rates. Questions concerning these findings and other issues surrounding the regulation led the FAA Associate Administrator for Regulation and Certification to renew research efforts on the relationship between age, experience and pilot performance. Approach. Information will be presented about the status of ongoing research within the FAA concerning the "Age 60 Rule". Research studies were designed to improve upon the historical methods of investigation, as well as to pursue research recommendations from groups of experts that had previously reviewed the questions. The first study consolidates existing historical databases (The NTSB's Accident data base, the FAA Airmen Certification database, and the FAA Medical database) in a replication and extension of the Golaszewski study. Analyses of pilot age, experience, and accidents will be conducted to assess the relationship. Subsequent studies assess the feasibility of using new or existing psychological and performance assessment methodologies for predicting subtle or age-related cognitive deficits in pilots. Conclusions. The purpose of these studies is to improve upon historical research methodologies that have purported to establish a relationship between age and accidents. Findings from the three investigations will be used to reassess the status of the "Age 60 Rule".

Froom, P. (1994). The risks of piloting with advanced age. *Journal of Community Health*, 19, 71-72.
Abstract
The author argues against the proposal that pilot over age 60 should have more frequent physical examinations. A primary problem with determining whether a pilot is fit to fly is that there is no existing definition of acceptable risk. Some have supported a 1% rule. This refers to a 1% chance of sudden incapacitation during the course of a single year, or one in 864,000 hours. In discussing a proposal for the development of a multivariate

logistic function to predict 60 year old pilots who have a greater risk for sudden incapacitation, the author feels that a problem with this approach is that above 55 the risk factors are no longer good predictors of future morbidity or mortality. The author recommends that evaluations of pilots over 60 be based on actual performance, rather than more frequent medical examinations.

Gander, P.H., De Nguyen, B.E., Rosekind, M.R., & Connell, L.J. (1993). Age, circadian rhythms, and sleep loss in flight crews. *Aviation, Space, and Environmental Medicine*, 64, 189-195.

Abstract
Age-related changes in trip-induced sleep loss, personality (n=205), and the pre-duty temperature rhythm (n=91) were analyzed in crews from various flight operations. Eveningness decreased with age (subjects aged 20-30 were more evening-type than subjects over 40). The minimum of the baseline temperature rhythm occurred earlier with age (earlier in subjects aged 30-50 than in subjects aged 20-30). The amplitude of the baseline temperature rhythm declined with age (greater in subjects aged 20-30 than in subjects over 40). Average daily percentage sleep loss during trips increased with age. Among crewmembers flying long haul flight operations, subjects aged 50-60 averaged 3.5 times more sleep loss per day than subjects aged 20-30. These studies support previous findings that evening types and subjects with later peaking temperature rhythms adapt better to shift work and time zone changes. Age and circadian type may be important considerations for duty schedules and fatigue countermeasures.

Glazer, I. (1992). Pilot aging policies in international airlines. Paper presented at the 63rd Annual Scientific Meeting of the Aerospace Medical Association, Miami Beach, FL. Abstract in *Aviation, Space, and Environmental Medicine*, Vol. 63, p. 428, 1992.

Abstract
Introduction. For decades regulatory agencies adhered to an arbitrary upper age limit for pilots engaged in passenger operations. Based on these rules and other considerations, airlines set up contractual agreements with unions and/or individual pilots. With the advent of modern diagnostic techniques and operational monitoring these rules and contracts were recently challenged. Development. Stress should be put on medical-physiological criteria rather than purely chronological arbitrary limits. Performance capability is essential in determining one's fitness as a pilot. Medical technology provides new diagnostic techniques, which enable us to predict with better confidence that a pilot will not become suddenly incapacitated especially where the cardiovascular system is concerned. The degradation of a pilot's perceptual, psychomotor and intellectual functioning which is expected in the aging process may be detected and assessed with a great measure of confidence by physicians, co-workers and family and documented during simulator performance and line checking. In a relatively small airline like EL-AL the medical officers and flight operation supervisory staff know each pilot personally and in many cases are familiar with the family environment. This enables them to detect occasionally some hidden stresses. EL-AL maintains the long-established mandatory retirement of operating crew members at age of sixty. However, it was recently agreed (as first officers only) on a yearly contract provided they fulfil the medical and operational criteria. This meets the current government regulations and we

feel confident that no undue risk is involved. Similar arrangements exist in a few other airlines. Our first year's experience will be discussed.

Golaszewski, R.S. (1993). Additional analysis of general aviation pilot proficiency. Unpublished report prepared by Gelman Research Associates (GRA), Jenkintown, PA.
Abstract
This report provides information developed as a result of expanded analyses of pilot accident rates that were initially reported in 1991. Information is provided for three general aviation pilot groups, based on class of medical certification and other occupation data.. Pilots who reported their occupation as an airline pilot, navigator or flight engineer were not included in any of the groups. Statistical analyses were conducted on the data. Accident rates for professional pilots holding a Class I Medical Certificate evidenced a general decline in accident rates through age 40-49 after which there was a gradual increase. Accident rates for professional pilots who hold a Class II medical Certificate increased with age. Pilots in both these groups averaged over 400 hours a year. The third group, which involved general aviation pilots with Class I and II medical certificates, averaged less than 100 flight hours per year, had higher accident rates than the other two groups, and evidenced a decline in accident rates across age.

Golaszewski, R. S. (1991) General Aviation Safety Studies Preliminary Analysis of Pilot Proficiency. Report prepared by Abacus Technology Corporation, Chevy Chase, MD. In association with Gelman Research Associates (GRA), Jenkintown, PA.
Abstract
The study was designed to look at the relationship between pilot characteristics (age and gender), experience (recent and total flight hours), and accidents. Accident data from 1983-1985, 1987, and 1988 were used in the analyses. The following were excluded from the database: airline pilots, student pilots, aero-applicators, airmen who were not pilots (e.g. air traffic controllers), and pilots who reported no recent or total flight hours. Accident data were compiled for three groups of pilots: Group A – professional pilots with a Class I medical certificate; Group B – professional pilots with a Class II medical certificate and flight instructors with either a Class I or Class II medical certificate; and Group C – pilots of all classes who were not professional pilots. Accident rates for Group A pilots declined from 17-19 through 40-49 after which rates increased. Rates for Group B increased in a linear fashion from 17-19 through 60-69. Group C pilots exhibited a general increase in accident rates through age 50-59 then declined for the 60-69 age group. Gender did not appear to have a significant influence on accident rates. Recent Flight Time (RFT) displayed a good relationship with accident rates, rates declined as RFT increased. A similar decline in accidents was evident when considering Total Flight Time (TFT). The author points to several interactions between RFT, TFT, and pilot group. Recommendations for additional analyses are provided.

Guide, P.C., & Gibson, R.S. (1991). An analytical study of the effects of age and experience on flight safety. *Proceedings of the Human Factors and Ergonomics Society 35th Annual Meeting*, pp. 180-184.
Abstract (DS)

This study was designed to determine the relationship between age, experience, and general aviation accidents. Using several aviation data bases (NTSB, AOPA, FAA, and COMSIS Research Corporation) the authors analyzed accident rates in 5-year increments from 20 to 60. Different accident statistics were used to review rates for ATPs, Commercial Pilots, and active private pilots. The influence of annual hours flown was also investigated. A discussion of the implications of age and experience on aviation safety was provided.

Hardy, D.J., & Parasuraman, R. (1997). Cognition and flight performance in older pilots. *Journal of Experimental Psychology: Applied*, 3, 313-348.
Abstract
The authors reviewed studies of cognitive proficiency and flight performance. Age-group differences were found in pilots in perceptual motor skills and memory and, to a lesser extent, in attention and problem solving. Flight experience does not alter this age-related decline, with the possible exception of the metacognitive skill of time sharing. Age-group differences in flight performance are most evident in the secondary task of air traffic control communications. Age-related differences in current measures of pilot cognition are minimally predictive of primary measures of flight performance (flight simulation and accident rates). A model of cognition and flight performance is proposed involving higher order factors that tap into pilot knowledge structure, including mental workload and workload management, mental models, and situation awareness.

Hardy, D.J., Mouloua, M., Molloy, R., Dwivedi, C.B., & Parasuraman, R. (1999). Monitoring of automation failures by young and old adults. *Proceedings of the Eighth International Symposium on Aviation Psychology*, Columbus, OH, pp. 1382-1387.
Abstract
This study was designed to look at the performance of younger (18 to 30 years) and older (61 to 77 years) adults on the Multi-Attribute Task Battery (MAT), a multi-task flight simulation task. Two dual-task situations were involved, system monitoring and tracking or system monitoring and resource management. System malfunctions were corrected either manually or automatically. However, periodically the automation routine would fail to detect a system malfunction, requiring that the operator detect and correct the malfunction. Performance was assessed across a block of 9, 10-min blocks under the automation condition. The detection rate of malfunctions was significantly lower under automation as compared with the manual condition. In contrast to expectations, older adults did not perform more poorly on the task than younger subjects. The lack of a difference in the performance of younger and older adults may be due to the fact that the processing capacity demands were not sufficiently high or that older adults were not susceptible to automation-related “complacency”.

Hardy, D.J., Slick, D.J., Satz, P., D'Elia, L.F., Uchiyama, C.L., & van Gorp, W.G. (1998). Neuropsychological test performance in middle-aged aviation pilots. Paper presented at the Annual Meeting of the American Psychological Association, San Francisco, CA.
Abstract
Cognitive performance was examined in a large sample (N=228) of middle-aged professional pilots. Pilots, who included commuter and test pilots as well as flight instructors, completed neuropsychological tests that assessed attention and concentration, inhibitory processes, psychomotor speed and coordination, and verbal and visual-spatial learning and memory. Regression analyses showed an age-related decline in these cognitive skills. The finding of an age-related decline in these professional pilots is compatible with the aviation literature and with other research showing that experience does not protect against decline in certain fundamental cognitive skills. Pilots' age-related cognitive decline appeared gradual and linear with no evidence of an abrupt decline around 60 years of age. Large individual differences were also evident. To the extent that cognition is related to pilot flying skills, these results question the efficacy of an age-based retirement rule for pilots such as the "Age 60 Rule."

Hilton Systems, Inc. (1994). *Age 60 rule research, Part I: Bibliographic database*. (Tech. Rep. No. DOT/FAA/AM-94/20). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine.
Abstract
As part of their research contract with the FAA to study issues related to the "Age 60 Rule" for pilot mandatory retirement, Hilton Systems, Inc. in collaboration with Lehigh University faculty and research facilities, complied this extensive bibliography. Topics included pilot aging, performance, health, and physiological factors, as well as other aviation and pilot related topics. Citations were included from a variety of sources including international and military studies. The bibliography was organized in three sections. The first section presents a bibliographic listing on the above topics. The second section provides a listing of publications by authors active in related fields. Finally, the third section provides citations from the driving literature.

Hyland, D.T., Kay, E.J., & Deimler, J.D. (1994). *Age 60 rule research, Part IV: Experimental evaluation of pilot performance*. (Tech. Rep. No. DOT/FAA/AM-94/23). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine.
Abstract
This report was a deliverable from the research contract with Hilton Systems, Inc. on the FAA's mandatory retirement for pilots operating under Federal Aviation Regulations Part 121, the "Age 60 Rule." The purpose of this study was to examine the feasibility of developing an individually-based pilot performance assessment, as well as design an experimental methodology to empirically examine the relationship between pilot aging and performance. Pilot performance was measured with both domain-dependent, as well as domain-independent assessments to test a decrement with compensation model of expertise and aging. Computerized cognitive test batteries, CogScreen and WOMBAT, were selected as the domain-independent measures. Flitescript and whole task performance in the B727 simulator were domain-dependent measures. Forty B727-rated

pilots were recruited from air carriers and the FAA. Pilots were males between the ages of 41 and 71 years (M=53.9, sd=8.1). All pilots had a minimum of 5,000 hours of total flight time with a wide range of total and recent hours in type. Three simulator scenarios were designed to assess pilot performance on routine, challenging, and emergency/abnormal maneuvers. Simulator performance measures were based on a deviation score and an evaluator rating. The relationships between the following measures were assessed by examination of the correlations between: 1) flying experience and simulator performance, 2) predictor test scores and simulator performance, 3) interrelationships between the predictor tests, and 4) age, flying experience, predictor test scores and simulator performance. Finally, pilot perceptions of each measure were assessed. CogScreen total composite scores were significantly correlated with evaluator ratings on emergency/abnormal maneuvers. Neither WOMBAT nor Flitescript were found to correlate with simulator performance. Pilot age was significantly correlated with performance on the predictor tests. A pattern of inter-correlations among pilot age, CogScreen and simulator performance was discussed.

Hyland, D.T., Kay. E.J., Deimler, J.D. & Gurman, E.B. (1994). *Age 60 rule research, Part II: Airline pilot age and performance –A review of the scientific literature.* (Tech. Rep. No. DOT/FAA/AM-94/21). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine.

Abstract

This review of the literature establishes the scientific foundation for subsequent studies on the Age 60 Rule research conducted under a contract with Hilton Systems, Inc. The scientific literature relevant to the two separate scientific approaches required by the contract is reviewed. The document first provides a review of the "Age 60 Rule," as well as the theoretical and methodological considerations critical to the study of aging and the assessment of individual pilot performance. A proposed model is presented to form a framework for the research. Pilot behaviors affected by aging and/or experience are reviewed. Specific performance assessment batteries are reviewed in detail in Appendix A. Issues related to measuring complex pilot performance are discussed. Recommendations and criteria for developing a performance methodology are presented. The second part of the literature review provides a discussion of the issues related to the analyses of existing data to assess the relationship between pilot age, experience and accident rates. This section provides a critical review of existing analyses and presents recommendations for an improved analytic methodology.

Hyland, D.T. (1993). Experimental evaluation of aging and pilot performance. *Proceedings of the 7th International Symposium on Aviation Psychology*, Columbus, OH, pp. 389-393.

Abstract

This is a condensed version of the information provided in the OAM Technical Report by Hyland, D.T.,Kay, E.J., and Deimler, J.D. (1994). *Age 60 rule research, Part IV: Experimental evaluation of pilot performance*. (Tech. Rep. No. DOT/FAA/AM-94/23).

Jones, D.R. (1992). Mental health aspects of the aging flyer. Paper presented at the 63rd Annual Scientific Meeting of the Aerospace Medical Association, Miami Beach, FL. Abstract in *Aviation, Space, and Environmental Medicine*, Vol. 63, p. 427, 1992.
Abstract
As fliers age, their attitude toward flying changes. The nature of this change is shaped by the original motivation to fly, and also by experience: aircraft accidents, deaths, other losses, marriage, divorce, children, job tension, finances, etc. Aging takes its own toll of perception of health, loss of "invulnerability," physical endurance, sense of slow reaction time or inability to respond to sudden novel stimuli. The rate of lessened functions differs, as does the sense of their loss and the utility of coping skills. If these skills fail, the results may be dangerous denial, depression, counter-phobic activity, fear of flying, or other pathology. Aeromedical practitioners should be familiar with these patterns, and should know how to use careful history-taking and skilful mental status evaluations to elicit information about possibly harmful patterns of adaptation and behavior.

Kay, E.J., Hillman, D.J., Hyland, D.T., Voros R.S., Harris, R.M., & Deimler, J.D. (1994). *Age 60 rule research, Part III: Consolidated database experiments final report.* (Tech. Rep. No. DOT/FAA/AM-94/22). Washington, DC: Federal Aviation Administration, Office of Aviation Medicine.
Abstract
This report was a primary deliverable from the research contract with Hilton Systems, Inc. on the FAA's mandatory retirement for pilots operating under Federal Aviation Regulations Part 121, the "Age 60 Rule." The purpose of this study was to examine existing data to assess the relationship between pilot age, accident rate, and experience. Three existing data bases were integrated on a single computer platform: 1) the FAA Airmen Certification file, 2) the FAA Medical History file, and 3) the National Transportation Safety Board (NTSB) Accident data base. The report represents a discussion of the methodological issues with studies in aging and reviews prior research. Limitations of utilizing these data sets are discussed. The methodological approach was developed from these considerations. Hilton Systems replicated and extended analyses from previous studies, including statistical analyses. The report describes outcomes from analyses conducted to answer a series of questions examining the relationship between age and accident rates for pilots holding Class I, Class II, and Class III medical certificates. Recent and total flight time are utilized as a measure of risk exposure. The results present a converging body of evidence, which fails to support a hypothesis that accident rates increase at or about the age of 60 years.

Kay, G.G. (1995). *CogScreen – Aeromedical Edition: Professional Manual*. Odessa, FL: Psychological Assessment Resources, Inc. (PAR).
Abstract
This manual describes the development of a computerized cognitive-screening test battery that was developed as part of a nearly 8-year effort for the FAA. It was designed to detect subtle changes in cognitive functioning and thus can serve "…as a specific neurocognitive test battery for use in the medical recertification evaluation of pilots with known or suspected neurological and/or psychiatric conditions. (pg. 1)." The manual provides an overview of the development of CogScreen, the subtests and measures,

software/hardware requirements, test administration procedures, scoring, reliability and validation, and interpretation. Chapter 8 contains information relative to the influence of demographic characteristics on CogScreen performance, including the influence of age (pgs. 39-40). The normative data are based on the administration of CogScreen-AE to nearly 600 commercial pilots in the U.S. Efforts were made to enroll pilots in equal numbers for each of six age groups (less than 35 years, 35-39 years, 40-44 years, 45-49 years, 50-54 years, and over 54 years). Age accounted for 9% or more of the variance in test performance for only five measures: SDC Thruput, SAT Instruction Speed, VSC Thruput, DTT Previous Number Dual Accuracy, and SAT Discovery Thruput. When combined together the multiple correlation between the variables an age yielded an R of .49, accounting for 24% of the variance.

Landy, F.J. (1992). *Alternatives to chronological age in determining standards of suitability for public safety jobs. Volume 1: Technical Report.* University Park, PA: Center for Applied Behavioral Sciences.

Abstract

The 1986 amendment to the 1967 Age Discrimination in Employment Act (ADEA) eliminated mandatory retirement ages for all workers except tenured college faculty and public safety officers (police, firemen and corrections officers). During the 7 years of this exception it was expected that studies would be initiated to determine if the reversal of the age requirement in these areas would impact public safety. An interdisciplinary team at Penn State University was tasked with determining if removing the mandatory chronological age retirement requirement for public safety positions would compromise public safety. This extensive report is comprised of 8 chapters, (a) an introduction that provides a historical overview and foundation for the study, (b) information gained through a data request sent to public safety agencies, (c) results of job task analyses of public safety positions, (d) the effects of aging on relevant abilities, (e) a review of tests of public safety abilities, (f) aging and medical status, (g) issues associated with establishing cut scores for individual and multiple abilities tests, and (h) an overall summary and recommendations. There is a fairly extensive discussion of the impact of sudden and subtle or accumulated deficits on public safety. For these occupations, the group concluded that "the risk of experiencing a catastrophic medical event that would compromise public safety is so small as to eliminate this factor in the debate regarding age-based retirement (pg. 17)." Second, they felt that available tests could provide better prediction of accumulated deficits than chronological age. This is in part due to the increased variability in performance associated with increasing age. Thirdly, existing testing technology was sufficient to permit the development of reliable and valid medical and ability tests for retirement decisions. Thus, the group recommended that the ADEA amendment exemption for public safety officers be removed.

Lassiter, D.L., Morrow, D.G., Hinson, G.E., Miller, M., & Hambrick, D.Z. (1996). Expertise and age effects on pilot mental workload in a simulated aviation task. *Proceedings of the Human Factors and Ergonomics Society 40th Annual Meeting*, 133-137.

Abstract

This study investigated the effects of expertise and age on cognitive resources relevant to mental workload of pilots engaged in simulated aviation tasks. A secondary task workload assessment methodology was used, with a PC-based flying task as the primary task., and a Sternberg choice reaction time task as the secondary task. A mixed design using repeated measures was employed, with age and expertise as between-subjects factors and workload as the within-subjects factor. Pilots ranging in age from 21 to 79 years and 28 to 11,817 hours of flight time served as subjects. Of interest was whether expertise would mitigate the adverse effect of aging on pilots' mental workload handling ability as defined by two measures of secondary task performance: choice reaction time and accuracy. Results indicated that expertise did mitigate the effects of age regarding secondary task accuracy. Implications of results are discussed, and directions for future research are presented.

Li, G. (1994). Pilot-related factors in aircraft crashes: A review of epidemiologic studies. Aviation, Space, and Environmental Medicine, 65, 944-952.

Abstract

The epidemiologic studies of pilot-related factors in aircraft crashes are reviewed with regard to: 1) study design and methods; 2) major findings; and 3) data and methodological issues. In the last 60 years, numerous studies have been conducted to examine the relationships of pilot characteristics to the risk of aircraft crashes. Much attention has been paid to pilots' medical condition, age, flight experience, and alcohol use. Most studies were based on crash analysis, using case reports and case series. Few studies have applied a formal, rigorous epidemiologic design. Planned case-control and cohort studies are extremely rare. In some cases, the deficiencies in study design and data analysis have resulted in controversial findings. More epidemilologic studies using state-of-the-art methodology are needed to identify various risk factors of aircraft crashes, to better understand the interrelationships among pilot, aircraft, and environment, and to develop and assess safety policies and other intervention programs.

Li, G. & Baker, S. P. (1994). Prior crash and violation records of pilots in commuter and air taxi crashes: a case-control study. Aviation, Space, and Environmental Medicine, 65, 979-985.

Abstract

With a case-control design, this study examined the relationships of crash/incident history, violation history, pilot age, flight experience, and recent flight time with the likelihood of being involved in commuter aircraft and commuter air taxi crashes. Cases (n=725) were pilots who had been involved in commuter aircraft or air taxi crashes during 1983-88, identified from the Nation Federal Aviation Administration (FAA) airmen information system, 1555 pilots were randomly selected as controls. Controls were frequency-matched with cases on medical class and calendar year. Different data bases within the FAA's airman information system were linked to ascertain information

about crash/incident and violation records in the previous 3 years, age, total fight time, and flight time in the prior 6 months. Multivariate logistic regression models were fitted to estimate odds ratios and evaluate dose-response effects, non-linear relationships, and interactions. Cases had significantly higher prevalence rates of prior crash/incident and violation records. The estimated odds ratio of being involved in a commuter aircraft or an air taxi crash was 1.7 (95% confidence Interval [CI], 1.3-2.4) for violation history. A "dose-response effect" was found with both crash/incident history and violation history, with higher odds ratios for pilots with crashes versus incidents or with more serious violations. Total flight time showed a diminishing protective effect. Either very small or very large recent flight time increased the risk of being involved in a commuter aircraft or an air taxi crash.

Lubner, M.E., Markowitz, J.S., & Isherwood, D.A. (1991). Rates and risk factors for accidents and incidents versus violations for U.S. airmen. *The International Journal of Aviation Psychology*, 1, 231-243.

Abstract

Rates and risks of general aviation accidents/incidents and violations were calculated employing case-control methodology. Cases, selected from FAA records of currently active airmen who had one or more accidents, incidents, for violations during 1982-1987, totaled 11, 548. Active controls were drawn from the FAA's `1987 Airmen's Registry (N = 666,801). A comparison of cases and controls was made by using five predictors: gender, age, medical certificate, airmen's certificate, and FAA region. All variables showed significant results as risks for, or as protective factors against, having an accident/incident, or violation. Some variables showed a greater risk for violations than for accidents/incidents. The period prevalence, or the number of existing cases divided by the average population, was 12.7 per 1,000 for accidents/incidents and 7 per 1,000 for violations. Limitations in verifying available data are discussed. It was recommended that accidents/incidents and violations should not be routinely aggregated because their epidemiology differs.

Martin-Saint-Laurent, A., Lavernhe, J., Casano, G., & Simkoff, A. (1990). Clinical aspects of inflight incapacitations in commercial aviation. *Aviation, Space, and Environmental Medicine*, 61, 256-260.

Abstract

Sudden incapacitations can affect a pilot and even a whole crew during a flight, preventing them from performing their task in complete safety. In some cases, they could even cause an accident. Our study examines the causes of sudden in-flight incapacitations in Air France pilots and flight engineers from 1968-88. Ten cases were reported out of a population of 1,800 cockpit crew, each flying an average of 600 h/year. While ages were not reported for the two crew incidents, ages of the involved pilots ranged from 39 to 55. These incapacitations were due to cardiac disorders (1 atrial fibrillation, 1 sinus tachycardia), epileptic attacks (2 generalized seizures), duodenal hemorrhages (2 cases), infection (1 case of severe vertigo due to viral labyrinthitis), metabolic disorders (1 case of hypoglycemia), and sometimes disorders affecting the whole crew (1 case of hypoxia due to a pressurization deficiency, 1 case of CO_2 intoxication caused by the inadequate packaging of a container refrigerated in dry ice).

Seven times out of ten, incapacitations occurred during cruising, twice during approach, and once on the ground before starting up, with closed door (CO_2 intoxication). Two of these incapacitations led to flight diversions. None of them caused an accident. In this series, incapacitations of a cardiac nature were rarer and less serious than those caused by gastrointestinal or neurological disorders. Prevention is based on detection during systematic medical check-ups, and on crews being trained to recognize subtle incapacitations early and to ensure that the flight continues safely when such a case occurs.

McFadden, K.L. (1997). Predicting pilot-error incidents of US airline pilots using logistic regression. *Applied Ergonomics*, 28, 209-212.
Abstract
In a population of 70,164 airline pilots obtained from the Federal Aviation Administration, 475 males and 22 females had pilot-error incidents in the years 1986-1992. A simple chi-squared test revealed that female pilots employed by a major airlines had a significantly greater likelihood of pilot-error incidents than did their male colleagues. In order to control for age/experience (total flying hours), risk exposure (recent flying hours) and employer (major/non-major airline) simultaneously, the author built a model of male pilot-error incidents using logistic regression. The regression analysis indicated that youth, inexperience and non-major airline employer were independent contributors to the increased risk of pilot-error incidents. The results also provide further support to the literature that pilot performance does not differ significantly between male and female airline pilots.

McKinnon, B.J. (1992). Physiologic "age" versus chronologic age in pilot medical standards. Paper presented at the 63rd Annual Scientific Meeting of the Aerospace Medical Association, Miami Beach, FL. Abstract in *Aviation, Space, and Environmental Medicine,* Vol. 63, p. 427, 1992.
Abstract
Introduction. In 1959 the FAA set into place the "Age 60 Rule." The "Age 60 Rule" requires mandatory retirement of commercial airline pilots at age 60. The intent was to reduce "human factor" in air accidents due to the age related deterioration in pilot performance. This has proven a highly controversial regulation in view of recent age discrimination legislation. The FAA defends the regulation on the basis that no other method has been proved accurate enough to screen pilots who wish to fly for commercial airlines after the age of sixty. The Thousand Aviator Study data is being reviewed, to determine if a physiologic standard can be derived through present medical screening modalities that can replace the present chronologic standard. Methods. Retrospective chart review of the Thousand Aviation Study subjects examining annual exercise stress test results as a predictor of cardiovascular health and performance. Results. Chart review presently on going, results not yet available. Conclusion. Sufficient data exist within the Thousand Aviator Study data base to determine if physiologic standards are a better indicator of age-related decline in performance as compared to a chronologic standard.

Mohler, S.R. (1992). The aging pilot question: history and technology status. Paper presented at the 63rd Annual Scientific Meeting of the Aerospace Medical Association, Miami Beach, FL. Abstract in *Aviation, Space, and Environmental Medicine*, Vol. 63, p. 427, 1992.
Abstract
Introduction. The widespread practices of unhealthy life-styles among large numbers of pilots in the 1940's and 1950's resulted in high prevalence among older pilots of cardiovascular and pulmonary disease. In addition, alcohol abuse and alcoholism are estimated to have affected as high as 1 in 5 pilots. The consequences of unhealthy life-styles began to particularly be manifested in middle age. In the 1940's and 1950's it was quite common to ascribe life-style caused diseases to the "aging process." Accordingly, although many pilots who did not practice "deleterious to health' life-styles, and who demonstrated a robust post middle-age health and vitality, a mandatory age cut-off to get rid of those whose life-style led to early disease seemed logical. Development. A mandatory age limit, thus, was institutionalized by Government for airline pilots in 1960, even though it was not the correct solution to the problems of alcoholism, smoking, poor nutrition, lack of exercise, obesity, and other life-style practices. Untreated hypertension was a major life-shortening problem also. Today. Modern diagnostic and treatment technology, along with knowledge of disease prevention, and modern performance assessment that provide objective simulator and flight measures, justify the abolition of the now-outdated age 60 cut-off limits for airline pilots flying under FAR 121.

Morrow, D. (1996). Experience Counts with Pilots. *Ergonomics in Design*, 4, 4-10.
Abstract
Outcomes from previous research are used to provide recommendations regarding the design of communications in future systems. It is important to standardize message organization. Use of a consistent communication order may serve to maximize expertise through development and use of schemas. Recommendations to reduce message length to promote understanding by both younger and older pilots. Visual communications in future data link systems may benefit older pilots. The order of message elements should remain consistent. The data link interface must be designed to minimize memory load on pilots. (Menu-based applications versus key-based systems). New procedures may be required to integrate the data link systems into the existing voice environment. It is important to consider age-sensitive design and training approaches in assisting older pilots in making a transition to the new highly automated flight decks.

Morrow, D., & Leirer, V. (1997). Aging, pilot performance, and expertise. In A.D. Fisk and W.A. Rogers (Eds.) *Handbook of Human Factors and the Older Adult*. San Diego, CA: Academic Press, Inc., pp. 199-230.
Abstract
Information from a review of the general literature on expertise and aging was used to develop predictions concerning the effects of age on pilot performance. Specific attention was focused on how experience may mitigate the effects of age on complex task performance. Analysis of the pilot age and performance literature is complicated by different ways of conceptualizing task complexity and experience. While pilot expertise doe reduce age differences for some tasks, there are aspects of performance that may not

benefit from experience. Research outcomes and theories of cognitive aging and expertise are then used to explore how the design of cockpit systems and training interventions can assist in minimizing the effects of age on pilot performance. Improved understanding the nature of the aviation environment can support efforts to identify the aspects of flight that are most influenced by aging and determine the countermeasures that would minimize the age-related effects.

Morrow, D., Leirer, V., & Altiere, P. (1992). Aging, expertise, and narrative processing. *Psychology and Aging*, 7, 376-388.

Abstract

In a study of how aviation expertise influences age differences in narrative processing, young and older pilots and nonpilots read and recalled aviation and general narratives. They chose referents for sentences referring to a protagonist or minor character mentioned 1 sentence (recent character) or 3 sentences (distant character) before this target sentence. All groups chose referents less accurately for sentences about distant and minor characters than about recent and protagonist characters, perhaps because these referents were less likely to be in working memory. Young readers and pilots were more accurate for distant and minor character target sentences in aviation narratives and recalled aviation narratives more accurately. Expertise did not reduce age differences. Expertise differences may reflect decreased demands on working memory capacity, and age declines may reflect reduced capacity.

Morrow, D., Leirer, V., Altieri, P., & Fitzsimmons, C. (1994). When expertise reduces age differences in performance. *Psychology and Aging*, 9, 134-148.

Abstract

Examined whether aviation expertise reduces age differences in a laboratory task that was similar to routine air traffic control (ATC) communication. In Exp 1, older (mean age 66.6 yrs) and younger (mean age 29.0 yrs) pilots and age-matched nonpilots read typical ATC messages (e.g., commands to change aircraft heading). After each message, they read back (repeated) the commands, which is a routine ATC procedure requiring short-term memory. Ss also performed less domain-relevant tasks. Expertise eliminated age differences in repeating heading commands but did not reduce age differences for the less relevant tasks. In Exp 2, expertise reduced but did not eliminate age differences in repeating heading commands from spoken messages. Results suggest that expertise compensates age declines in resources when the task is highly domain relevant.

Morrow, D., Leirer, V., & Yesavage, J.A. (1990). The influence of alcohol and aging on radio communication during flight. *Aviation, Space, and Environmental Medicine*, 61, 12-20.

Abstract

This study finds that alcohol and pilot age impair radio communications during simulated flight. Young (mean age 25 years) and older (mean age 42 years) pilots flew in a light aircraft simulator during alcohol and placebo conditions. In the alcohol conditions, pilots drank alcohol and flew after reaching 0.04% BAC, after reaching 0.10% BAC, and then 2, 4, 8, 24, and 48 h after they stopped drinking at 0.10% BAC. They flew at the same times in the placebo condition. Alcohol and age impaired communication-based and overall flying performance during and immediately after drinking. Most important, alcohol and age cumulatively impaired performance, since older pilots were more impaired by alcohol. Notably, performance was as impaired 2 h after reaching 0.10% BAC as it was at 0.10% BAC. Moreover, overall performance was impaired for 8 h after reaching 0.10% BAC.

Morrow, D., Leirer, V., Yesavage, J.A., & Tinklenberg, J. (1991). Alcohol, age, and piloting: Judgement, mood, and actual performance. *The International Journal of the Addictions*, 26, 669-683.
Abstract
Examined the effects of alcohol and age on self-assessment of performance and mood among 7 young (mean age 25.3 yrs) and 7 old (mean age 42.1 yrs) pilots who flew in a simulator during an alcohol and placebo condition. Ss rated confidence in ability to fly, mood, alertness, and intoxication before each flight and rated perceived workload and performance after each flight. As reported by D. Morrow et al (see PA, Vol 77:118750), alcohol had both acute and carry-over (ACO) effects for 8 hrs on actual flight performance, with greater acute impairment for older Ss. Older Ss were more aware than young Ss of ACO alcohol impairment up to 4 hrs after reaching a blood alcohol level of .10% and rated their performance as worse than young pilots in the alcohol but not the placebo condition. However, by 8 hrs, all Ss were unaware of impairment.

Morrow, D., Menard, W.E., & Stine-Morrow, E.A.L. (1999a). The influence of aging and expertise on pilot communication. Paper presented at the 10th International Symposium on Aviation Psychology, Columbus, OH.
Abstract
We examined the effects of age and expertise on a laboratory pilot communication task. Young (25-45yrs), middle-age (50-60) and older (60-80) pilots and nonpilots listened to ATC messages that described a route through an airspace, while referring to a map of the airspace. After each message, they read back the instructions and then answered a question about the aircraft's route. An earlier study found that expertise reduced age differences in readback accuracy, but did not reduce differences for tasks that were less related to piloting. In the present study, pilots and younger participants read back messages more accurately, but expertise did not reduce age differences for this measure. Pilots and younger participants also answered questions more accurately, and there was some evidence that age had less impact on pilots than on nonpilots for question accuracy.

Morrow, D.G., Menard, W.E., & Stine-Morrow, E.A.L. (1999b). Expertise and aging in pilot communication: The role of environmental support. Paper presented at the annual meeting of the Human Factors and Ergonomics Society, Houston, TX (October).
Abstract
81 pilots (28 young, 32 middle aged, 21 older) and 84 nonpilots (24 young, 32 middle, and 28 older) participated in a study of performance on memory capacity, processing speed, spatial ability, and response to recorded ATC messages that described routes to or from an airport. After each message, participants read back the instructions and responded to a probe. Participants could write down the message before reading back and refer to their notes when answering the probe. Age-related declines were evident in

memory capacity, processing speed and spatial ability. An increase was evident in verbal ability. An age by expertise interaction was significant for the spatial ability test. Pilots were more accurate in reading back the ATC messages than nonpilots. Younger participants were more accurate. Age by expertise interaction was significant. Performance was virtually perfect for pilots regardless of age. Age declines in ATC message readback accuracy were eliminated by expertise when participants could write down messages.

Morrow, D., Yesavage, J., Leirer, V., Dohlert, N., Taylor, J., & Tinklenberg, J. (1993). The time-course of alcohol impairment of general aviation pilot performance in a Frasca 141 simulator. *Aviation, Space, and Environmental Medicine*, 64, 697-705.
Abstract
14 young (aged 21-29 yrs) and 14 older (aged 31-51 yrs) male pilots were tested in a flight simulator during alcohol (AC) and placebo conditions. In the AC condition, Ss drank AC and were tested after reaching .10% blood alcohol level, and then 2, 4, 8, 24, and 48 hrs after they had stopped drinking. They were tested at the same times in the placebo condition. AC impaired overall performance. AC impairment also depended on the order in which Ss participated in the AC and placebo sessions, with larger decrements for the AC-placebo order than for the opposite order. A comparison of performance in the 1st AC session with performance in the 1st placebo session suggested that some Ss were more susceptible to AC than others. Older Ss tended to perform some radio communication tasks less accurately than younger Ss.

Morrow, D., Yesavage, J., Leirer, V., & Tinklenberg, J. (1993). Influence of aging and practice on piloting tasks. *Experimental Aging Research*, 19, 53-70.
Abstract
Examined how pilot age influences radio communication and routine flying tasks during simulated flight, and whether practice reduces age differences in these tasks. The communication task involved reading back and executing messages with 4 commands (heading, altitude, communication frequency, and transponder code). Routine flying tasks included takeoff, visual approach, and landing. 15 31-51 yr old (older) and 16 22-29 yr old (younger) private-license pilots flew 12 flights involving these tasks. Older pilots read back and executed controller messages less accurately. Age differences in communication performance were not reduced by practice, with older and young pilots improving at roughly the same rate across flights.

Mortimer, R.G. (1991). Some factors associated with pilot age in general aviation crashes. *Proceedings of the 6th International Symposium on Aviation Psychology*, Columbus, OH, pp. 770-775.
Abstract
A sample of 1034 NTSB Accident Brief reports for 1985/86 were analyzed to discern age differences of pilots in the characteristics of general aviation airplane accidents. Pilots aged 60 or more were more involved in taxiing accidents and those under 30 more in the maneuvering phase. In combination with pilot exposure data from another study and the FAA accident data for 1986, the accident rates of pilots aged 60 or more and

younger pilots were estimated. Those aged 60 or more had an accident rate about twice that of the younger pilots.

Odenheimer, G. (1999). Function, flying, and the age-60 rule. *Journal of the American Geriatrics Society*, 47, 910-911 (Editorial).
Abstract
Comments on the article by J. A. Yesavage et al (see record 1999-03251-005) concerning aging and simulated flight performance in aviators. Yesavage et al's study was intended to "provide data on the relationship of age to performance on simulated flight in order to address the Age-60 rule." However, 2 important study design issues may prevent such application. A brief history of the Federal Aviation Administration's Age-60 rule is provided.

Office of Technology Assessment. (1990). *Medical risk assessment and the Age 60 Rule for airline pilots*. Subcommittee on Investigations and Oversight, Committee on Public Works and Transportation, U.S. House of Representatives, Washington, DC.
Abstract
OTA was tasked by the Subcommittee on Investigation and Oversight of the House Committee on Public Works and Transportation to review current approaches to medical risk assessment and determine their relevance to evaluate pilot performance capabilities. Data from Golaszewski, 1983 and the NTSB, 1990 indicate that older pilots with Class I or II medical certificates have higher accident rates. Sudden pilot incapacitation has not been a factor in airline accidents. Concerns were expressed regarding the ability to detect subtle effects of aging that may impact pilot performance. Improved neuropsychological measures of cognitive performance are needed and validated against pilot performance to identify pilots who are at greater risk. While providing recommendations for improved procedures for the identification of medical conditions that may affect pilot performance, OTA indicated that those procedures would not be sufficient to ensure that the current level of safety would be maintained if the Age 60 Rule were abolished. In addition, they would more than tripe the costs of the medical examination for the pilot. OTA concluded their report by pointing out other economic issues associated with abolishing the Age 60 rule, including training, salaries, labor contracts, and legal action.

Parasuraman, R., Mouloua, M., & Molloy, R. (1994).   Monitoring automation failures in human-machine systems. In M. Mouloua and R. Parasuraman (Eds.), *Human performance in automated systems: Current research and trends* (pp. A4a5-49). Hillsdale, NJ: Lawrence Erlbaum Associates.
Abstract
Examined the ability of pilots and non-pilots to monitor automation on a flight simulation task. Performance was assessed in a multi-task environment using the modified Multi-Attribute Task (MAT) Battery. Performance involved the compensatory tracking, system monitoring and fuel-management tasks. While performance of the monitoring task under manual conditions resulted in a 75% detection rate, detection declined to about 55% (pilots) and 32% (non-pilots) under the automation conditions. While pilots evidenced better performance under the automation condition both groups evidenced poorer performance than during the manual monitoring condition. Performance declines under

automation become apparent as soon as 20 minutes into the task. Performance could not be attributed to the spatial position of the tasks. A period of time during which the task is reallocated to the manual condition assisted subjects (pilots and non-pilots) in improving detection during a subsequent period of automation.

Pelegrib, C., Maho, V., & Amalberti, R. (1995). Pilot age and training performance. In *Aviation Psychology: Training and Selection: Proceedings of the 21st Conference of the European Association for Aviation Psychology*. Brookfield, VT: Avebury Aviation, pp. 354-363.

Abstract

The authors describe a typology of difficulties encountered in pilot training that were associated with pilot age. Information was gathered from pilots of ages 20-62 who were transitioning to the Airbus A320. While failures in the 29 to 44 year old groups ranged from 2 to 5%, the rate increased to 8% in the 45-48 and around 16% for those 49 and older. The extent to which difficulties are encountered is, in part, related to the degree to which experience on system and task management can be transferred. The authors provide evidence that pilots who had a greater number of flight time hours on the same aircraft type often experience greater learning difficulties with transitioning to a new aircraft type. They reported that 41% of the pilots failing at the evaluation were over age 44 and had over 2,200 flight hours on their latest aircraft type. This class represented only 16% of the total population. Efforts have been devised to develop “adapted attitudes in training” to assist older pilots. The authors also feel that older pilots may have more sophisticated risk management strategies based on the meta-knowledge they have acquired through experience.

Rebok, G.W., Grabowski, J.G., Baker, S.P., Lamb, M.W., Willoughby, S., & Li, G. (1999). Pilot age and performance as factors in aviation crashes. Poster presented at the Annual Meeting of the American Psychological Association, Boston, MA.

Abstract

This study focused on age differences in pilot performance factors involved in aviation crashes. A historical cohort of 3,592 pilots aged 45 to 54 years in 1987 who flew air carriers and air taxi flights was constructed and followed up through the FAA’s airmen information system. All crash records for the study subjects between 1983 and 1997 were identified and obtained from the NTSB’s aviation crash investigation data base. Comparisons were made between crashes involving pilots aged 40 to 47 years (n=65), 48 to 55 years (n=73), and 56 to 63 (n=27). Of the pilot performance factors examined, 19% involved inattentiveness, 15% involved flawed decisions, 13% involved mishandling winds and/or runway conditions, and 12% involved mishandling aircraft kinetics. Pilot performance was a factor in 58% of the older pilots’ crashes compared with 71% of the younger pilots’ crashes, and 74% of the middle-aged pilots’ crashes. For older pilots, mishandling aircraft kinetics was most likely to involve inadvertent stalls. There appear to be no significant age differences in the pilot performance factors contributing to aviation crashes. The role of cognition and other causative factors in the flight performance of older pilots needs further empirical study.

Reinhart, R.O. (1990). Compulsory retirement at Age 60. In, *Challenges and choices in corporate aviation safety*. Proceedings of the 35th annual corporate aviation safety seminar. Arlington, VA: Flight Safety Foundation, pp. 12-17.

Abstract

The author provides a brief review of aspects of the existing aero-medical standards. He indicates that the Age 60 rule is not a part of medical regulations. The author feels that if the age restriction were removed, the medical evaluation would need to be expanded to include a new set of tests involving reaction time, cognitive thinking ability, processing, and judgment skills. The difficulty will be in establishing the performance standard for those tests to determine whether the pilot is safe versus unsafe. The author relates his personal experience in having recommendations not to hire candidates that were based on psychological tests being rejected by the company. Another concern is who has the final responsibility for giving approval to the pilot to fly at an advancing age, the aviation medical examiner, the FAA, the company, or pilot. While against the principle of using a stated age for mandatory retirement, the author feels that it is necessary until an acceptable alternative program can be developed.

Salive, M.E. (1994). Evaluation of aging pilots: Evidence, policy, and future directions. *Military Medicine*, 159, 83-86.

Abstract

Current Federal Aviation Administration (FAA) regulations require that pilots of large commercial passenger and cargo aircraft be under age 60. However, the requirement does not apply to other pilots and the courts have ruled that mandatory retirement of test pilots at age 60 violates the Age Discrimination in Employment Act. FAA medical standards establish three levels of medical qualification, which require certain age-specific screening tests. This paper reviews the epidemiologic and clinical evidence relevant to the evaluation of aging pilots. This evidence is compared and contrasted with the current FAA requirements and past recommendations of the American Medical Association, the Institute of Medicine, and the Office of Technology Assessment. An opportunity exists to assess the class I examination and other tests through the consent decree covering aging test pilots. Another course of action would be to implement special issuances for older pilots.

Salthouse, T.A. (1994). Age-related differences in basic cognitive processes: Implications for work. *Experimental Aging Research*, 20, 249-255.

Abstract

Investigated relationships among age, experience, and work performance. In 3 studies, architects, users of computer-assisted design and manufacturing systems, and a general sample of adults completed cognitive tests assessing spatial abilities. Experience did not moderate the relationship between age and basic cognitive processes. However, there was little evidence that aging is associated with lower levels of work performance, perhaps because increased experience often comes with age.

Salthouse, T.A. (1990). Influence of experience on age differences in cognitive functioning. *Human Factors,* 32, 551-569.

Abstract

To the extent that adult age differences in measures of cognitive performance have implications for functioning outside the psychological laboratory, the question of the role of experience as a potential moderator of these differences becomes extremely important. Three categories of research relevant to this issue are reviewed, and methodological limitations of each type of research are discussed. Although it is frequently asserted that experience minimizes cognitive differences associated with aging, the evidence currently available does not appear consistent with a strong experiential moderation of age-related effects in cognitive performance. However, the paucity of relevant studies and the methodological weaknesses of those that do exist preclude a definitive conclusion at the present time. Additional research with improved methodology is necessary before strong conclusions can be reached concerning effects of experience on age differences in cognition.

Serwer, A.M. (1990). Compulsory retirement at Age 60—II. In, *Challenges and choices in corporate aviation safety*. Proceedings of the 35th annual corporate aviation safety seminar. Arlington, VA: Flight Safety Foundation, pp. 18-26.

Abstract

The author argues against the age 60 rule. A review of both the legal challenges to the rule and some of the flight safety implications of retaining the rule is provided. The author concludes by indicating that the rule has not future, and that, in agreement with Dr. Stanley R. Mohler, there are only three factors that should be considered when determining if someone should continue to fly: freedom from an impairing disease, ability to perform, and motivation to fly.

Simons, M., Valk, P.J.L., Krol, J.R., & Holewijn, M. (1996). Consequences of raising the maximum age limit for airline pilots. *Proceedings of the Third ICAO Global Flight Safety and Human Factors Symposium (Human Factors Digest No. 13).* No. CIRC 266-AN/158, 248-255.

Abstract

The Dutch Aeronautical Inspection Directorate, in1978, fixed the maximum age for airline pilots, in the Netherlands, at 60. In its draft European regulations, the Joint Aviation Authority (JAA) has proposed that this age limit be raised to 65, subject to certain conditions. When the "Age 60" rule was introduced, it was assumed, based on evidence of a greater cardiovascular disease risk and cognitive impairment in the 60-65 age group, that there would be a greater risk of in-flight incapacitation, which might result in an aircraft accident. Analysis of the US accident statistics shows that the accident rates of pilots in the 60-65 age group do not differ from those of most other age groups. In general, the US medical certification database evidence confirmed a higher incidence of cardiovascular disease and cognitive impairment over the age of 40. However, there were large individual variations in the degree of risk and the level of cognitive functioning. The authors indicate that an require an active screening policy, based on the epidemiological data from the age group to which the pilot belongs should ensure that the safety risk associated with increasing the maximum age to 65 is minimal.

The authors recommend that the current medical examination for each age group incorporate standardized risk screening procedures and an occupational history. This report describes the procedures for standard and additional screening of airline pilots.

Stoklosa, J.H. (1992). Review of performance, medical and operational data on pilot aging issues. Paper presented at the 63rd Annual Scientific Meeting of the Aerospace Medical Association, Miami Beach, FL. Abstract in *Aviation, Space, and Environmental Medicine,* Vol. 63, p. 428, 1992.
Abstract
Introduction. An extensive review of the literature and studies relating to performance, medical, operational, and legal data regarding pilot aging issues was performed in order to determine what evidence there is, if any, to support mandatory pilot retirement. Popular misconceptions about aging, including the failure to distinguish between the normal aging process and disease processes that occur more frequently in older individuals, continue to contribute to much of the misunderstanding and controversy that surround this issue. Results. Review of medical data related to the pilot aging issue indicate that recent improvements in medical diagnostic and treatment technology have made it possible to identify to a high degree individuals who are at risk for developing sudden incapacitating illness and for treating those with disqualifying medical conditions. Performance studies revealed that after controlling for the presence of disease states, older pilots are able to perform as well as younger pilots on many performance tasks. Review of accident data showed that older, healthy pilots do not have higher accident rates than younger pilots and, indeed, evidence suggests that older pilots have an advantage in the cockpit due to higher experience levels. The Man-Machine-Mission-Environment interface of factors can be managed through structured, supervised, and enhanced operations, maintenance, flight reviews, and safety procedures in order to ensure safe and productive operations by reducing the margin of error and by increasing the margin of safety. Conclusion. There is not evidence indicating any specific age as an arbitrary cut-off point for pilots to perform their duties. A combination of regular medical screening, performance evaluation, enhanced operational maintenance, and safety procedures can more effectively ensure a safe pilot populations than can a mandatory retirement policy based on arbitrary age restrictions.

Stone, L.W. (1993). The aging military aviator: A review and annotated bibliography. U.S. Army Aeromedical Research Laboratory Report No. AD-A265341; USAARL-93-11.
Abstract
Studies suggest that aging is another factor which may affect performance of military pilots. Although these aviators generally are better-educated and healthier than their age peers in the general population, they, too, are subject to insidiously deteriorating physiological and sensory systems, a slowly increasing likelihood of acute pathologies, and a general slowing with age—all within the age range of military pilots. Reductions in some parameters might be offset to some degree by experience and maturity; however, age-related changes and the effects therefrom vary more between individuals in any age group than between the groups themselves. The real problem, though, is that we still do not know what effect, if any, age-related changes have on performance of military

aviators. Neither is there a concerted effort to provide the aging pilot with a coping strategy for the approaching situation.

Stuck, A.E., van Gorp, W.G., Josephson, K.R., Morgenstern, H., & Beck, J.C. (1992). Multidimensional risk assessment versus age as a criterion for retirement of airline pilots. *Journal of the American Geriatric Society*, 40, 526-532.
Abstract
Discusses whether airline pilots (APs) over the age of 60 yrs pose a hazard to aviation safety and whether risk assessment could replace age-based retirement. A computer-assisted literature search (MEDLINE) identified original articles bearing on these questions. None of the studies on cognitive (COG) testing of APs provided specific data on the relationship between AP age and COG function. COG test batteries have not been sufficiently validated for predicting the safety in performance of experienced APs. No studies have been conducted on the prevalence of dementia in APs. Short mental status instruments used for dementia screening in elderly patients have shown insufficient predictive value in APs, since these tests do not assess crucial abilities required for piloting performance, such as COG flexibility or sequencing.

Taylor, J.L., O'Hara, R., Mumenthaler, M.S., & Yesavage, J.A. (In Press). Relationship of CogScreen-AE to flight simulator performance and pilot age. *Aviation, Space, and Environmental Medicine.*
Abstract
Objectives: We report on the relationship between CogScreen-Aeromedical Edition (AE) factors scores and flight simulator performance in aircraft pilots aged 50-69. Methods: 100 licensed, civilian aviators (average age 58 +/- 5.3 years) performed aviation tasks in a Frasca model 141 flight simulator and the CogScreen-AE battery. The aviation performance indices were: (1) staying on course, (2) dialing in communication frequencies, (3) avoiding conflicting traffic, (4) monitoring cockpit instruments, (5) executing the approach, and (6) a summary score, which was the mean of these scores. The CogScreen predictors were based upon a factor structure reported by Kay (1995), that comprised 28 CogScreen scores. Through principal components analysis of Kay's nine factors, we reduced the number of predictors to five composite CogScreen scores: Speed/Working Memory (WM), Visual Associative Memory , Motor Coordination, Tracking, and Attribute Identification. Results: Speed/WM scores had the highest correlation with the flight summary scores. Significant predictors, in order of entry, were: Speed/WM, Visual Associative Memory, Motor Coordination, and Tracking (p's <..05). Pilot age was found to significantly improve prediction beyond that which could be predicted by the four cognitive variables. In addition, there was some evidence for specific ability relationships between certain flight component scores and CogScreen scores, such as approach performance and tracking errors. Conclusions: These data support the validity of CogScreen-AE as a cognitive battery that taps skills relevant to piloting.

Taylor, J.L., Dolhert, N., Morrow, D., Friedman, L., & Yesavage, J.A. (1994). Acute and 8-hour effects of alcohol (0.08% BAC) on younger and older pilots' simulator performance. *Aviation, Space, and Environmental Medicine*, 65, 718-725.

Abstract
Examined the acute and 8-hr effects of alcohol on aviators after achieving a lower target blood alcohol concentration of .08%. 14 younger pilots (mean age 27.6 yrs) and 14 older pilots (mean age 60.3 yrs) flew a flight simulator in a scenario that included Air Traffic Control communications and emergencies. Ss were tested during alcohol and placebo conditions at 3 times: pre-drink, during acute intoxication, and 8 hrs post-drink. Two performance measures showed significant effects related to alcohol: cockpit monitoring and communication. Cockpit monitoring was poor when Ss were intoxicated, with recovery at 8 hrs. Younger Ss made more communications while intoxicated, and there was no significant recovery after 8 hrs.

Taylor, J.L., Yesavage, J.A., Morrow, D.G., Dohlhert, N., Brooks, J.O., & Poon, L.W. (1994). The effects of information load and speech rate on younger and older aircraft pilots' ability to execute simulated air-traffic controller instructions. *Journal of Gerontology: Psychological Sciences*, 49, P191-P200.
Abstract
Studied memory for orally presented information in 15 younger (aged 21-34 yrs) and 15 older (aged 51-74 yrs) pilots who heard recorded air-traffic controller (ATC) messages in the context of 6 simulated flights. The ATC messages varied in length (3 vs 4 items), speech rate (235 vs 365 wpm), and type of command (course commands consisting of headings and altitudes vs radio/transponder commands consisting of radio frequencies and transponder codes). Older Ss made more execution errors on average, and the age difference was greater for the radio/transponder commands, which contained more unique digits than the course commands. Although longer message lengths and faster speech rates led to higher error rates, the increases were not more marked in older Ss. Backward digit span was correlated with communication performance, but older Ss' lower level of accuracy was not explainable in terms of differences in digit span.

Tsang, P.S. (1992). A reappraisal of aging and pilot performance. *International Journal of Aviation Psychology*, 2, 193-212.
Abstract
Reviews age effects on 4 cognitive functions (perceptual processes, memory, problem solving and decision making, and psychomotor coordination) deemed essential to pilot performance. Cognitive slowing and resource reduction are discussed as general causes for age-related deficits. Research has relied heavily on laboratory findings due to the scarcity of systematic studies with pilots. Limitations in generalizing from the general population to the pilot population and from lab findings to operational significance are noted. Some studies indicate that the increased expertise of older pilots may have a moderating influence on the effects of aging such that older pilots have at least as good or better safety records than younger, more inexperienced pilots.

Tsang, P. (1997). A microanalysis of age and pilot time-sharing performance. In D. Harris (Ed.), *Engineering psychology and cognitive ergonomics* (Vol. One: Transportation Systems). Brookfield, VT: Ashgate, pp. 245-251.
Abstract

Studied the effects of age on time-shared performance on four task pairs for 4 subjects in each of four age groups (30-39, 40-49, 50-59, and 60-69). Pilots with 700-8,000 total hours of flight experience comprised half of the subject population. The tasks were selected on their relevance to flying and their sensitivity to age. The four task pairs varied in the extent to which they required similar resources. Following initial sessions where subjects performed on the tasks individually and dually with equal priority, procedures were implemented to shift the priority of each component of the dual tasks. The author found significant age-related reductions in time-sharing efficiency. Subjects were able to modify resource allocations in response to the priority instructions. In that the older pilots performed more like the middle aged non-pilot group, there was evidence that expertise may have compensated for some of the effects of age. The lack of a differential effect of age on control speed led to the conclusion that the dual task interference, decrement in time sharing, and expertise compensation were not motor in nature.

Tsang, P. (1997). Age, flight experience, time-sharing performance, and perceived workload. *Proceedings of the 9th International Symposium on Aviation Psychology*, Columbus, OH, pp. 42-46.
Abstract
Studied the relative contribution of age to performance on several cognitive tasks individually and under time-sharing conditions. Analyses were conducted to determine the effects of age along with selected psychometric test scores and experience data. Information was also gained regarding the relative workload associated with the various task conditions. When compared to flight experience, age was the more powerful predictor of performance. However, when first considering the influence of other psychometric variables (intelligence and perceptual-motor speed) age explained only a small additional amount of the variance in task performance. The author concludes that there are other variables that provide a better predictor of single and time-shared task performance than age. Ratings of subjective workload were similar for older and younger subjects.

Tsang, P.S. (1997). Age and pilot performance. In R.A. Telfer and P.J. Moore (Eds.), *Aviation training: Learners, instruction and organization*. Brookfield, VT: Avebury, pp. 21-40.
Abstract
The author reviews the effects of age on the cognitive functions judged by many to be important factors in overall pilot performance (perception, memory, problem solving and decision making, psychomotor, and time-sharing). This included a discussion of laboratory tasks, simulator performance, and accident rate as a function of age. Age-related changes are evident in many of the cognitive tasks associated with pilot performance. Across age cohorts, an increase in variability of performance is also commonly noted. While the age effect is generally more evident in complex tasks, expertise in time-sharing may reduce the negative effects of age. In reviewing the accident literature and simulator performance, the author concludes that it is difficult to identify age effects on pilot performance.

Tsang, P.S. (1999). Retention and transfer to time-sharing skill as a function of age and flight experience. Paper presented at the 10th International Symposium on Aviation Psychology, Columbus, OH, May.

Abstract

Retention and transfer of time-sharing skill (prioritizing and handling of multiple tasks) were examined. Fourteen participants between the ages of 30 and 70 performed two task batteries of flight-relevant laboratory tasks approximately two years apart. Fourteen naive participants performed only the second battery. Half of the participants were pilots considered to have expertise in time-sharing. Results showed that the older participants retained their time-sharing skill as well as the younger participants. Pilots time-shared better than nonpilots in general. Positive transfer of time-sharing suggested that time-sharing is a skill that has a general component such as executive management that develops and improves with training and is transferable across time-sharing contexts.

Tsang, P.S., & Shaner, T.L. (1995). Age, expertise, structural similarity, and time-sharing efficiency. *Proceedings of the Human Factors and Ergonomics Soceity 39th Annual Meeting*, pp. 124-128.

Abstract

The authors investigated the relationship between age, expertise, and structural similarity on time-sharing. Subjects ranged in age from 20 to 80, half of the 90 were pilots the other half non-pilots. A total of five dual tasks involving horizontal tracking and tasks that assessed various aspects of cognitive flight performance. Outcomes revealed that time-sharing efficiency increased as structural similarity of the tasks declined. Age reduced time-sharing efficiency. Expertise in time-sharing tasks of pilots moderated the effects of age on time-sharing performance on the cognitive tasks.

Tsang, P.S., & Shaner, T. L. (1998). Age, attention, expertise, and time-sharing performance. *Psychology and Aging*, 13, 323-347.

Abstract

Time-sharing efficiency and resource allocation from a group of pilots with expertise in time-sharing and a group of nonpilots (ages 20-79 years) were examined. Participants performed 5 dual tasks that represented different degrees of structural similarity as characterized by the structure-specific resource model. Age, expertise, and structural similarity were found to interactively affect time-sharing performance through attentional resources. Age-related deficits in time-sharing were evident under conditions of intense attentional demands and when precise control was required. Modest expertise modulation of the age effects is likely to increase with more domain-specific time-sharing. The structure-specific resource model provided a useful framework for interpreting the relationship between aging and time-sharing performance.

Tsang, P.S., Shaner, T.L., & Schnopp-Wyatt, E.N. (1995). *Age, attention, expertise, and time-sharing performance* (Technical Rep. No. EPL-95-1). Wright State University, Department of Psychology, Engineering Psychology Laboratory.

Abstract

Most of the content of this technical report is already covered in the journal articles or presentations.

Tsang, P.S., & Voss, D.T. (1996). Boundaries of cognitive performance as a function of age and flight experience. *International Journal of Aviation Psychology*, 6, 359-377.
Abstract
Examined the effects of age and expertise on 2 components of time-sharing (TS) performance (TS efficiency and attention allocation control) in pilots and nonpilots. Due to the experience of juggling multiple tasks, 90 pilots were recruited as TS expert Ss. The Ss in 20-39, 40-59, and 60-79 age groupings performed a battery of cognitive tasks that represented different aspects of piloting. Six single tasks were used: horizontal axis tracking task, vertical axis tracking task, 2 Planikin tasks, and 2 Sternberg memory tasks. Results showed that TS performance was age sensitive; that older Ss generally did not perform as closely to the optimized standard as younger Ss. However, expertise appeared to have some moderating influence on the age effects. Further, analysis of the overlap of the response distributions from different age groups suggested that age alone was not a definitive discriminator of an individual's TS skill.

Vincenzi, D.A., & Mouloua, M. (1999). Monitoring automation failures: Effects of age on performance and subjective workload. In M. W. Screbo & M. Mouloua (Eds.) *Automation Technology and Human Performance: Current Research and Trends.* Mahwah, NJ: Lawrence Erlbaum Associates.
Abstract
The study was designed to evaluate the effects age and high task load on monitoring performance in a multi-task environment. A revised version of the Multi-Attribute Task (MAT) Battery, involving compensatory tracking, system monitoring, and fuel-management tasks was used in the study. The simulated monitoring task involved tracking temperature and pressure for two simulated engines. Subjects were all non-pilots - 12 young adults (18 to 25) and 12 older adults (over age 65). Following a 10-minute training session that involved manual control of all three tasks, subjects performed manually on the compensatory tracking and fuel-management tasks, while system monitoring was handled through automation. Each of the three follow-on sessions was 30 minutes in length. Detection of temperature/pressure malfunctions was similar for the two age groups under manual conditions (70% - elderly and 76% - younger). Following a sharp drop in detection under the automated monitoring condition, younger subjects evidenced some improvement across sessions 2 and 3. Older subjects evidenced a gradual lower of their detection rates. Younger adults performed significantly better than the older adults. Subjective workload on the task was comparable for the two groups.

Williams, T.F. (1991). Testimony to a Joint Hearing of the House Select Committee on Aging and the Education and Labor Subcommittee on Employment Opportunities on the problem of age discrimination in employment, Tuesday, 24 September, Washington, D.C.
One of the participants in the NIA 1981 study. Expresses strong opposition to the "age 60" rule. Is of the opinion that there are a number of tests that could be applied to pilots

over 60 in the same way they are used with pilots under age 60. (NEED TO REVIEW AND REVISE)

Williams, J.D., & Williams, J.A. (1991). Commercial pilots and mandatory retirement. In S.R. Deitz, and W.E. Thoms (Eds.) *Pilots, personality, and performance*. New York: Quorum Books, pp. 125-143.
Abstract
In light of a Supreme Court decision that established guidelines for mandatory retirement when age is a bona fide occupational qualification (BFOQ), the authors review three court decisions regarding the Age 60 Rule. A brief review of the broader scientific literature on cognition and aging is provided, along with a review of the physiological and motorical aspects of aging. Information is also provided regarding the relationship between age and performance in pilots, with an emphasis on the 1981 National Institute on Aging Pilot Study. In conclusion the authors state that "…some airline pilots are capable of continuing in that capacity reasonably safely beyond age sixty (p. 139)."

Yakimovich, N.V., Strongin, G.L., Govorushenko, V.V., Schroeder, D.J., & Kay, G.G. (1994). CogScreen as a predictor of flight performance in Russian pilots. Paper presented at the 65th Annual Scientific Meeting of the Aerospace Medical Association, San Antonio, TX. Abstract in *Aviation, Space, and Environmental Medicine*, Vol.65, p. 443, 1994.
Abstract
Introduction. The extent to which measures of cognitive function correlate with skilled aviation performance was the subject of a Russian-American research project. Methods. Assessment of flight performance was obtained from analysis of flight parameter violations available from the plane's flight data recorder. Data were obtained for 75 Captains over 3 years in two commercial aircraft (IL-86 and TU-154). An index of the seriousness of violations, developed by 5 chief pilots, and cumulative flight hours, were used to provide a weighted estimate of flight performance. Pilots were administered the Cyrillic version of the CogScreen test battery under standard conditions. Results. Based on these scores, pilots were divided into three groups: optimal (N=29), medium (N=26), and sub-optimal (N=20). Flight performance was found to be significantly correlated ($r=.30$ to $.17$, $p < .01$) with 11 CogScreen variables. Highest correlations were found for the Divided Attention, Shifting Attention, Backward Digit Span, and Matching to Sample subtests. Pilot age was highly correlated with flight performance ($r=.45$; $p < .001$). 50% of the pilots in the sub-optimal group were 56-60 years of age. Conclusions. The CogScreen test battery appears to be a good predictor of flight performance in an operational setting. Results suggest that particular attention be directed at assessment of pilots in the 56 to 60 year age group where there was a high rate of flight performance violations and low CogScreen performance.

Yesavage, J.A., Dolhert, N., & Taylor, J.L. (1994). Flight simulator performance of younger and older aircraft pilots: Effects of age and alcohol. *Journal of the American Geriatrics Society*, 42, 577-582.
Abstract

Determined if older pilots forget more about a learned flight task after a 10-mo delay than do younger pilots, and if the anticipated greater skill loss will lead the older pilots' performance to be more disrupted by alcohol. Ss were 14 21-34 yr old and 13 51-69 yr old pilots who performed a flight simulator task that they had previously learned but not practiced for several months. Ss were tested at 2 time points, either in an alcohol or a placebo condition. Detrimental effects of alcohol were found on the main outcome measure, both at the acute and 8-hr post-drink testing. There were no significant performance differences between the older and younger Ss, nor differences in susceptibility to alcohol either while intoxicated or during hangover.

Yesavage, J.A., Taylor, J.L., Mumenthaler, M.S., Noda, A., & O'Hara, R. (1999). Relationship of age and simulated flight performance. *Journal of the American Geriatrics Society*, 47, 8199-823.
Abstract
Determined the relationship between age and aviator performance on a flight simulator. The sample consisted of 100 aviators (aged 50-69 yrs). Pilots were tested on a Frasca 141 flight simulator (Urbana, IL), linked to a UNIX-based IRIS 4D computer (Silicon Graphics, Mountain View, CA), which both generated graphics of the environment in which the pilots flew and collected data concerning the aircraft's flight conditions. It was found that increased age was significantly associated with decreased aviator performance on a flight simulator. Although there was a significant relationship between increased age and decreased aviator performance, age explained 22% or less of the variance of performance on different flight tasks; hence, other factors are also important in explaining the performance of older pilots.