American Journal of Epidemiology

Vol. 157, No. 10
Printed in U.S.A.
DOI: 10.1093/aje/kwg071

Age, Flight Experience, and Risk of Crash Involvement in a Cohort of Professional Pilots

Guohua Li[1,2], Susan P. Baker[1,2], Jurek G. Grabowski[1], Yandong Qiang[1], Melissa L. McCarthy[1], and George W. Rebok[3]

[1] Department of Emergency Medicine, Johns Hopkins School of Medicine, Baltimore, MD.
[2] Center for Injury Research and Policy, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD.
[3] Department of Mental Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD.

Received for publication August 29, 2002; accepted for publication November 27, 2002.

Federal aviation regulations prohibit airline pilots from flying beyond the age of 60 years. However, the relation between pilot age and flight safety has not been rigorously assessed using empirical data. From 1987 to 1997, the authors followed a cohort of 3,306 commuter air carrier and air taxi pilots who were aged 45–54 years in 1987. During the follow-up period, the pilots accumulated a total of 12.9 million flight hours and 66 aviation crashes, yielding a rate of 5.1 crashes per million pilot flight hours. Crash risk remained fairly stable as the pilots aged from their late forties to their late fifties. Flight experience, as measured by total flight time at baseline, showed a significant protective effect against the risk of crash involvement. With adjustment for age, pilots who had 5,000–9,999 hours of total flight time at baseline had a 57% lower risk of a crash than their less experienced counterparts (relative risk = 0.43, 95% confidence interval: 0.21, 0.87). The protective effect of flight experience leveled off after total flight time reached 10,000 hours. The lack of an association between pilot age and crash risk may reflect a strong "healthy worker effect" stemming from the rigorous medical standards and periodic physical examinations required for professional pilots.

accidents, aviation; aging; aviation; cohort studies; safety; wounds and injuries

Abbreviations: CFR, Code of Federal Regulations; FAA, Federal Aviation Administration; NTSB, National Transportation Safety Board.

Federal aviation regulation 14 CFR 121.383 (c) (Title 14, Code of Federal Regulations) mandates that no person aged 60 years or older may serve as a pilot in command or copilot on commercial passenger and cargo flight operations with 10 or more passenger seats or 7,500 payload-pounds of capacity. This regulation, commonly known as the "age-60 rule," has been the subject of continuing controversy since it became effective in 1960. At issue is the policy's scientific basis, as well as legal and economic considerations such as age discrimination, pension planning, and career advancement. The "age-60 rule" was promulgated out of concerns about the potential detrimental effects of aging on pilots' safety performance, particularly when the aviation industry switched from propellers to high-speed and high-capacity jet-powered aircraft. One of the stated reasons for imposing the age limit on airline pilots was that the risk of acute and incapacitating medical conditions, such as heart attack and stroke, increases with advancing age and these age-related medical conditions cannot be accurately predicted at the individual level (1). Opponents of the "age-60 rule" have argued that airline pilots, as a highly select group, have significantly lower overall mortality and mortality from cardiovascular diseases than the general population (2–5) and that the risk of a crash resulting from sudden incapacitation of the pilot in command is negligible, particularly in the presence of other crew members in the cockpit (6, 7). It is estimated that the risk that an airline crash will result from cardiac incapacitation of the pilot is less than 1 per 8 billion pilot flight hours (8). There has been no crash among major US airlines in which sudden incapacitation of the pilot was found to be a contributing factor.

Reprint requests to Dr. Guohua Li, Department of Emergency Medicine, Johns Hopkins School of Medicine, 1830 East Monument Street, Suite 6-100, Baltimore, MD 21205 (e-mail: ghli@jhmi.edu).

The effects of aging on cognitive functions and piloting skills have been studied extensively (9, 10). The literature shows consistently that whereas domain-independent cognitive functions such as sensory, perceptual, and psychomotor skills deteriorate progressively with age, performance in most flight-related tasks such as decision-making, tracking, takeoff, and landing does not differ significantly between older and younger pilots (11–13). One of the few flight-related tasks with age-related declines is the ability to respond to communication. Specifically, older pilots are found to be less accurate than younger pilots in reading back and executing tape-recorded air traffic control commands, especially long and fast speech commands (14, 15). The age-related decline in performing communication tasks is attributed to decreased working memory capacity in the elderly (14). It is evident that flight experience can eliminate age-related deficits in the performance of certain communication tasks (e.g., repeating heading commands) and mitigate the adverse effects of aging on the performance of less domain-relevant tasks (16–19). Most of these studies, however, were conducted under controlled laboratory conditions using flight simulators and were cross-sectional in essence. Therefore, their value for assessing age-related differences in risk of crash involvement is limited.

The fundamental question concerning the controversy of the "age-60 rule" is whether pilots' risk of crash involvement changes significantly in the process of aging. Answering this question requires analyzing prospectively collected exposure and safety record data for a large sample of pilots. Previous studies examining the relation between pilot age and risk of involvement in general aviation crashes have reported contradictory results. Mohler et al. (20) found that the crash rate per capita for pilots aged 60 years or older was similar to rates for younger pilots, whereas Booze (21) reported that the per-capita crash rate for pilots aged 70 years or older was four times the rate for those younger than age 20. Findings from these studies were limited by the cross-sectional design and by the lack of individual-level data on exposure to flight (22). In this study, which was based on longitudinal data, we aimed to assess the associations of age and flight experience with risk of crash involvement in a birth cohort of professional pilots.

MATERIALS AND METHODS

Study population

The Federal Aviation Administration (FAA) categorizes civil aviation into three major groups: 1) general aviation, which encompasses all noncommercial aircraft flying under Title 14, Code of Federal Regulations, Part 91 (14 CFR Part 91); 2) major airlines operating under 14 CFR Part 121, which until 1997 covered all flights of aircraft having more than 30 passenger seats; and 3) commuter air carriers and air taxis, consisting of scheduled and "on-demand" commercial flights of craft with 30 or fewer seats operated under 14 CFR Part 135. (Since March 20, 1997, 14 CFR Part 135 includes only aircraft with fewer than 10 passenger seats.) This study was conducted among pilots flying 14 CFR Part 135 operations. We chose commuter air carrier and air taxi pilots as the study population for several reasons. First, the fatal crash rate per pilot flight hour for commuter air carriers and air taxis is 10–45 times the rate for major airlines (23), making it possible to examine the actual crash experience over time in a fixed cohort with a reasonable sample size and study power. Second, the "age-60 rule" did not apply to commuter air carrier and air taxi pilots until 1999, making it possible to examine the safety performance of these pilots beyond age 60 years. Third, commuter air carrier and air taxi pilots with Class I medical certificates meet the same medical standards as major airline pilots; thus, data from this study population should be more relevant to major airline pilots than data obtained from general aviation pilots.

There were approximately 65,000 pilots flying 14 CFR Part 135 operations in 1987, according to the FAA's Airman Information System (24). Eligible for this study were pilots who met the following criteria in 1987: 1) holding a Class I medical certificate; 2) being employed by one of the 14 CFR Part 135 airlines identified from the FAA's list of airline employers; 3) being 45–54 years of age; 4) flying for business or both business and pleasure; 5) listing "pilot" or "commercial pilot" as one's occupation; 6) having 20 or more hours of flight time in the previous 6 months; and 7) having 500 or more hours of total flight time. These criteria were used to create a birth cohort of active commuter air carrier and air taxi pilots. A total of 3,306 pilots met these criteria, and all were included in the study.

Data collection

The study subjects were followed up from 1987 to 1997 through several surveillance systems operated by the FAA and the National Transportation Safety Board (NTSB). The Aviaton Medical Examiner System is a computerized database of medical certificates. There are three classes of medical certificates. The Class I certificate has the strictest medical standards; it is primarily for major airline pilots and is renewed every 6 months. Class II has less strict medical standards than Class I; it is for other commercial aviation pilots and is renewed every 12 months. Class III has the least strict medical standards; it is for private and student pilots and is renewed every 2 years. FAA regulations require that an active commuter air carrier or air taxi pilot possess a valid Class I or Class II medical certificate. These certificates can only be issued by aviation medical examiners, who are physicians authorized by the FAA to perform physical examinations for pilots. The medical examination for pilots is intended to detect functional changes and disorders that may increase the risk of sudden incapacitation or that otherwise might have a detrimental effect on flight safety. Biannual medical certification data obtained for these study subjects included information on pilot's name, date of birth, gender, occupation, self-reported total flight time, flight time in the previous 6 months, and medical conditions. We merged biannual medical certification data for the 11-year study period for each pilot by matching the data on personal identifying information (pilot certificate number, name, and date of birth).

The NTSB is mandated to report all aviation crashes ("accidents" in NTSB terminology) using a standardized procedure and a set of data forms. The NTSB defines a crash as an event associated with the operation of an aircraft that results in personal death or serious injury or substantial aircraft damage. Central to the NTSB crash investigation documents is the data form called the "Factual Report Aviation," which provides detailed information about the incident, the environment, the pilot, and the aircraft. We scanned the NTSB database to ascertain all crash records that involved the study subjects. A total of 66 crashes involving the study subjects were identified. Investigative data for each of these crashes were coded and merged with medical certification data.

We searched the National Death Index to determine the vital status of the study subjects during the follow-up period. A total of 105 study subjects died during the follow-up period, including 27 who were fatally injured in aviation crashes. Information about the date and cause of death was added to the medical certification and crash records to form a longitudinal database.

Data analysis

The outcome of primary interest was involvement in an aviation crash. Since a pilot is at risk of crash involvement only when he or she flies, a reasonable expression of crash risk is the number of crashes per pilot flight hour, which is derived from the epidemiologic concept of person-time. Self-reported flight hours in the previous 6 months recorded on medical certificates were used to estimate cumulative exposure to flight during the follow-up period. Explanatory variables included in the analysis were age, sex, total flight time at baseline, use of corrective lenses for distant or near vision, and pathology codes indicating specific medical conditions. Total flight time is widely used as a measure of piloting experience (22, 25).

Follow-up data for the study subjects were censored if 1) the subject was involved in an aviation crash; 2) the subject's medical certificate was downgraded from Class I to Class II or Class III; 3) the subject died; or 4) the subject stopped renewing his or her medical certificate because of retirement or another reason. Data analysis proceeded from exploratory inquiry to statistical modeling. At the exploratory stage, crash rates per pilot flight hour were computed according to pilot characteristics. Differences in crash rates were assessed using relative risks and 95 percent confidence intervals. Effects of potential interactions between explanatory variables on crash risk were examined by stratification analysis. At the modeling stage, the accumulated flight time to a crash during the follow-up period was analyzed as a function of the explanatory variables using the proportional hazards model developed by Cox (26). The model is based on the assumption that the accumulated flight time to a crash follows an exponential distribution; therefore, the relative risk associated with a given explanatory variable is constant over time. This assumption, however, can be voided if the explanatory variable is treated as being time-dependent (27). In our analysis, pilot age was centered at 45 years and entered into the model as a time-dependent variable. The effects of total flight time at baseline and other explanatory variables on the outcome measure were also evaluated using the proportional hazards model. The goodness of fit of the model selected was assessed by means of the likelihood ratio test. Data analyses were performed using Statistical Analysis System software, version 8 (SAS Institute, Inc., Cary, North Carolina).

TABLE 1. Baseline characteristics of a sample of commuter air carrier and air taxi pilots, United States, 1987

Characteristic	No. of subjects (*n* = 3,306)	%
Age (years)		
45–49	2,272	68.7
50–54	1,034	31.3
Sex		
Male	3,263	98.7
Female	43	1.3
Total flight hours at baseline		
<5,000	711	21.5
5,000–9,999	991	30.0
10,000–14,999	1,057	32.0
≥15,000	547	16.5
Flight hours in previous 6 months		
<200	812	24.6
200–299	803	24.3
300–399	731	22.1
≥400	960	29.0
Use of corrective lenses for distant or near vision		
Yes	2,238	67.7
No	1,068	32.3
Any medical pathology code		
Yes	459	13.9
No	2,847	86.1

RESULTS

Baseline characteristics

Of the 3,306 pilots studied, 99 percent were male and 69 percent were aged 45–49 years (table 1). The mean age was 48.5 years (standard deviation, 2.8). On average, the pilots had 9,749 hours of total flight time (standard deviation, 5,766) and 287 flight hours (standard deviation, 144) in the 6 months prior to the baseline date. Sixty-eight percent of the pilots required corrective lenses for distant or near vision (table 1). The overwhelming majority (86 percent) of the pilots did not have any health problems at baseline. Of all pathology codes, 38 percent were codes for cardiovascular conditions (e.g., cardiac murmur and hypertension), followed by hernias (17 percent) and defective hearing (17 percent).

Crash rate

By the end of follow-up, 1,632 (49.4 percent) pilots had been censored from the study; of those, 66 were involved in

TABLE 2. Crash rates per million pilot flight hours among commuter air carrier and air taxi pilots, according to baseline characteristics, United States, 1987–1997

Characteristic	Cumulative pilot flight hours	No. of crashes	Rate/million pilot flight hours	Relative risk	95% confidence interval
Age (years)					
45–49	9,539,500	46	4.82	1.00	
50–54	3,386,714	20	5.91	1.22	0.67, 1.99
Sex					
Male	12,808,778	66	5.15	1.00	
Female	117,436	0	0.00	0.00	
Total flight hours at baseline					
<5,000	2,569,600	21	8.17	1.00	
5,000–9,999	3,578,018	12	3.35	0.41	0.18, 0.80
10,000–14,999	4,273,722	22	5.15	0.63	0.34, 1.17
≥15,000	2,504,874	11	4.39	0.54	0.22, 1.06
Use of corrective lenses for distant or near vision					
Yes	8,354,718	36	4.31	1.00	
No	4,571,496	30	6.56	1.52	0.92, 2.47
Any medical pathology code					
Yes	1,775,752	7	3.94	1.00	
No	11,150,462	59	5.29	1.34	0.72, 4.85

aviation crashes, 513 downgraded their medical certificates to Class II or III, nine died of natural causes or non-aviation-related injuries while holding a Class I medical certificate, and 1,044 stopped renewing their medical certificate because of retirement or other reasons. During the 11-year study period, the pilots flew a total of 12.9 million hours and had 66 crashes while holding Class I medical certificates, yielding an overall rate of 5.1 crashes per million pilot flight hours. (No pilot had more than one crash while holding a Class I medical certificate.) Pilots with less than 5,000 hours of total flight time were nearly twice as likely as their more experienced counterparts to be involved in a crash (8.2 vs. 4.4 crashes per million pilot flight hours; $p < 0.001$). Other baseline characteristics were not significantly associated with crash risk (table 2).

Crash rates remained fairly stable as pilots' ages rose from 45–49 years to 55–59 years (table 3). During follow-up, 578 pilots continued flying after reaching age 60. There were three crashes that involved pilots aged 60 years or older. Although the crash rate at age 60–64 years—11.0 crashes per million pilot flight hours—was approximately twice as high as the rate at younger ages, the age-related difference in crash rates was not statistically significant (table 3).

Adjusted relative risk

Results from multivariate modeling were consistent with those from exploratory analysis. Age, which was entered into the proportional hazards model as a time-dependent variable with a quadratic term, did not exhibit a significant effect on crash risk. In comparison with pilots with less than 5,000 total flight hours at baseline, those with 5,000–9,999 total flight hours at baseline had a 57 percent lower risk of crash involvement (relative risk = 0.43, 95 percent confidence interval: 0.21, 0.87). However, an additional increase in total flight time was not associated with any further reduction in crash risk (figure 1).

DISCUSSION

This study provided comprehensive empirical data on the intricate relations among aging, flight experience, and safety performance. The results indicated that flight safety, as mea-

TABLE 3. Crash rates per million pilot flight hours among commuter air carrier and air taxi pilots, by pilot age, United States, 1987–1997

Age (years)	Cumulative pilot flight hours	No. of crashes	Rate/million pilot flight hours	Relative risk	95% confidence interval
45–49	4,136,366	23	5.56	1.00	
50–54	5,594,906	24	4.29	0.77	0.43, 1.39
55–59	2,923,364	16	5.47	1.28	0.49, 1.84
60–64	271,578	3	11.05	2.02	0.00, 4.76

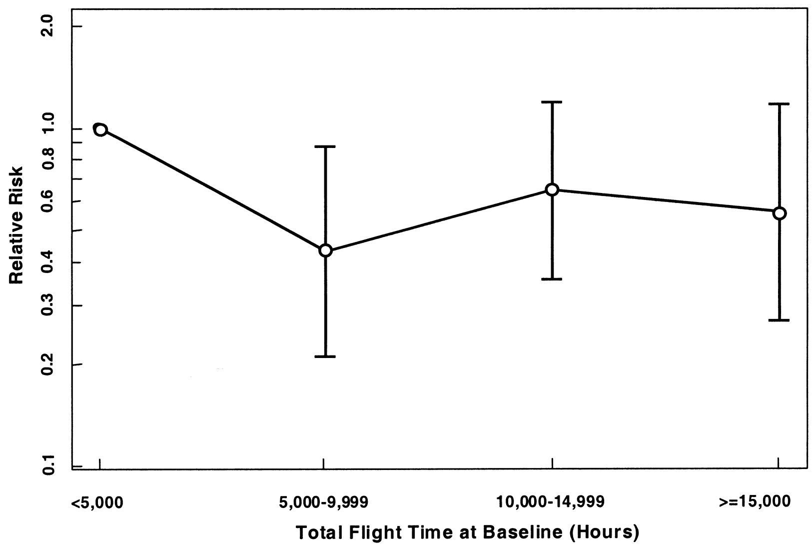

FIGURE 1. Age-adjusted relative risk of crash involvement according to baseline total flight time among commuter air carrier and air taxi pilots, United States, 1987–1997. Bars, 95% confidence interval.

sured by rates of crashes per million pilot flight hours, does not change significantly as pilots age from their late forties to their late fifties. Flight experience, as measured by total flight time, is a more important determinant of crash risk than aging. With adjustment for age, having 5,000 or more hours of total flight time at baseline reduced crash risk by more than 50 percent. The protective effect of flight experience on crash risk appeared to level off after total flight time at baseline reached 10,000 hours.

Theoretically, aging may influence pilots' safety performance through two conflicting pathways. On the one hand, in the process of aging pilots may become more vulnerable to various health problems and declines in cognitive function, potentially impairing piloting skills and increasing the propensity for crash involvement. On the other hand, aging may expose pilots to a reduced crash risk because of increased expertise, enhanced safety behavior, and greater job autonomy. Age, a measure of chronologic time, should by itself have little bearing on safety performance if variables indicating age-related changes, such as health status and flight experience, are taken into consideration.

In this study, we found that crash risk was not significantly associated with advancing age. The absence of an association between aging and crash risk was probably due to the "healthy worker effect" resulting from the rigorous medical standards and periodic physical examinations required for professional pilots. That is, pilots who experienced the most age-related declines in health and cognitive function were likely to have been screened out by the medical certification process, leaving the more physically and mentally fit in the workforce. The overwhelming majority of nondisqualifying medical conditions are minor health problems that are unlikely to have any discernible impact on safety performance. The association between aging and safety performance may have been further attenuated by the "safe worker effect." In addition to being healthy, pilots who continue flying at advanced ages are likely to have maintained a favorable safety record. Those with excess risk of crash involvement and violations are more likely to end their careers at younger ages because of disabling injuries and license terminations (6).

Lack of a significant aging effect on crash risk in this study does not necessarily mean that safety performance cannot be affected by aging. Rather, it implies that the current medical standards and physical examination system for professional pilots are adequate in ensuring flight safety. If the pilots who were screened out in the process of aging had remained on active duty, the adverse effect of aging on crash risk might well have emerged as significant.

The finding that flight experience has a protective effect against the risk of crash involvement is consistent with previous studies. In a case-control study conducted among commuter air carrier and air taxi pilots, Li and Baker (25) found that the risk of crash involvement decreases in a nonlinear fashion as total flight time increases. The safety benefit of total flight time is most pronounced in the early, experience-building stage. When total flight time reaches a certain threshold, the marginal benefit diminishes. This nonlinear relation between flight experience and safety performance has been documented in studies involving different pilot groups and using different research designs (25, 28–30).

It is known that flight experience can compensate to some degree for age-related declines in cognitive function and that overlearned complex tasks such as piloting are less susceptible to age-related deterioration than abilities to perform in novel situations (14, 16, 18, 19, 31, 32). This study provides empirical evidence that safety performance as measured by the crash rate per million pilot flight hours remains steady until age 60 years. Data for pilots beyond age 60 years were too scarce for results to be conclusive.

Although the target population in this study was commuter air carrier and air taxi pilots, the reported crash rates were based on all crashes experienced by the study subjects before they were censored, including 25 general aviation crashes. It is not uncommon for professional pilots to fly under general aviation regulations for pleasure and recreation while off-duty. The crash rate in general aviation is 4.5 times the rate for commuter air carriers and is about the same as that for air taxis (23). Since information on exposure to flight was unavailable for specific categories of aviation, we were unable to calculate crash rates separately for commuter air carriers and air taxis and for general aviation. It is possible that exposure to general aviation in this study population may increase in the process of aging because of increased leisure time. Given that two out of the three crashes that occurred at age 60–64 years involved general aviation flights, the crash rates for older ages reported in this study may have been somewhat overestimated. Additionally, crash risk in this study was assessed without consideration of the probable causes. Previous studies showed that pilot error is a contributing factor in 71 percent of commuter air carrier and air taxi crashes (33). There is little evidence that the prevalence of pilot error is significantly associated with age in professional pilots (33, 34). A study based on general aviation crashes revealed that older male pilots tend to make fewer errors, particularly poor decisions, than younger male pilots (35).

Age and flight experience are intractably interrelated over time. In the presence of longitudinal data, it is tempting yet unrealistic to partition aging effects from effects of other age-related variables, because, in the process of aging, few changes occur in isolation. Results of this study indicate that in the current context of rigorous medical standards and periodic physical examinations, commuter air carrier and air taxi pilots can maintain their safety record at least until age 60. The upper limit of safety age for professional pilots needs to be determined through more confirmatory epidemiologic data. In recent years, Japan and most European countries have revised regulations to allow airline pilots to fly until age 65 (36, 37). To carefully monitor and assess the safety and health of airline pilots over age 60 in these countries, an international surveillance system is warranted.

ACKNOWLEDGMENTS

This research was supported primarily by grant R01AG13642 from the National Institute on Aging and partly by grant R49CCR302486 from the Centers for Disease Control and Prevention.

The authors thank the Civil Aeromedical Institute of the Federal Aviation Administration and the Analysis and Data Division of the National Transportation Safety Board for data assistance.

REFERENCES

1. Institute of Medicine, National Academy of Sciences. Airline pilot age, health and performance. Washington, DC: National Academy Press, 1981.
2. Haldorsen T, Reitan JB, Tveten U. Aircraft accidents and other causes of death among Norwegian commercial pilots. Aviat Space Environ Med 2002;73:587–92.
3. Band PR, Le ND, Fang R, et al. Cohort study of Air Canada pilots: mortality, cancer incidence, and leukemia risk. Am J Epidemiol 1996;143:137–43.
4. Ballard TJ, Lagorio S, De Santis M, et al. A retrospective cohort mortality study of Italian commercial airline cockpit crew and cabin attendants, 1965–96. Int J Occup Environ Health 2002;8:87–96.
5. Kaji M, Tango T, Asukata I, et al. Mortality experience of cockpit crewmembers from Japan Airlines. Aviat Space Environ Med 1993;64:748–50.
6. Mohler SR. Reasons for eliminating the “age 60” regulation for airline pilots. Aviat Space Environ Med 1981;52:445–54.
7. Wilkening R. The age 60 rule: age discrimination in commercial aviation. Aviat Space Environ Med 2002;73:194–202.
8. Chapman PJ. The consequences of in-flight incapacitation in civil aviation. Aviat Space Environ Med 1984;55:497–500.
9. Hardy DJ, Parasuraman R. Cognition and flight performance in older pilots. J Exp Psychol Appl 1997;3:313–48.
10. Schroeder DJ, Harris HC, Broach D. Pilot age and performance: an annotated bibliography. Oklahoma City, OK: Federal Aviation Administration, Civil Aeromedical Institute, Human Resources Research Division, 2000.
11. Szafran J. Psychological studies of aging in pilots. Aerosp Med 1969;40:543–53.
12. Taylor JL, O’Hara R, Mumenthaler MS, et al. Relationship of CogScreen-AE to flight simulator performance and pilot age. Aviat Space Environ Med 2000;71:373–80.
13. Morrow D, Leirer V, Yesavage J. The influence of alcohol and aging on radio communication during flight. Aviat Space Environ Med 1990;61:12–20.
14. Morrow D, Yesavage J, Leirer V, et al. Influence of aging and practice on piloting tasks. Exp Aging Res 1993;19:53–70.
15. Taylor JL, Yesavage J, Morrow DG, et al. The effects of information load and speech rate on younger and older aircraft pilots’ ability to execute simulated air-traffic controller instructions. J Gerontol 1994;49:191–200.
16. Morrow D, Leirer V, Altieri P, et al. When expertise reduces age differences in performance. Psychol Aging 1994;9:134–48.
17. Morrow DG, Menard WE, Stine-Morrow EA, et al. The influence of expertise and task factors on age differences in pilot communication. Psychol Aging 2001;16:31–46.
18. Tsang PS, Voss DT. Boundaries of cognitive performance as a function of age and flight experience. Int J Aviat Psychol 1996; 6:359–77.
19. Tsang PS, Shaner TL. Age, attention, expertise, and time-sharing performance. Psychol Aging 1998;13:323–47.
20. Mohler SR, Bedell RH, Ross A, et al. Aircraft accidents by older persons. Aerosp Med 1969;40:554–6.
21. Booze CF Jr. Epidemiologic investigation of occupation, age, and exposure in general aviation accidents. Aviat Space Environ Med 1977;48:1081–91.
22. Li G. Pilot-related factors in aircraft crashes: a review of epidemiologic studies. Aviat Space Environ Med 1994;65:944–52.
23. Baker SP, O’Neill B, Ginsburg MJ, et al. The injury fact book. 2nd ed. New York, NY: Oxford University Press, 1992.
24. Civil Aeromedical Institute. 1987 aeromedical certification statistical handbook. Washington, DC: Federal Aviation Administration, 1988.

25. Li G, Baker SP. Prior crash and violation records of pilots in commuter and air taxi crashes: a case-control study. Aviat Space Environ Med 1994;65:979–85.
26. Cox DR. Regression models and life tables (with discussion). J R Stat Soc B 1972;34:187–220.
27. Breslow NE, Lubin JH, Marek P, et al. Multiplicative models and cohort analysis. J Am Stat Assoc 1983;78:1–12.
28. Bennett CT, Schwirzke M. Analysis of accidents during instrument approaches. Aviat Space Environ Med 1992;63:253–61.
29. Shuch HP. The influence of flight experience on midair collision risk perception. Accid Anal Prev 1992;24:655–60.
30. Borowsky MS, Wall R. Flight experience and naval aircraft mishaps. Aviat Space Environ Med 1983;54:440–6.
31. Yesavage JA, Taylor JL, Mumenthaler MS, et al. Relationship of age and simulated flight performance. J Am Geriatr Soc 1999;47:819–23.
32. Yesavage JA, Dolhert N, Taylor JL. Flight simulator performance of younger and older aircraft pilots: effects of age and alcohol. J Am Geriatr Soc 1994;42:577–82.
33. Li G, Baker SP, Grabowski JG, et al. Factors associated with pilot error in aviation crashes. Aviat Space Environ Med 2001; 72:52–8.
34. Li G, Baker SP, Lamb MW, et al. Human factors in aviation crashes involving older pilots. Aviat Space Environ Med 2002; 73:134–8.
35. Baker SP, Lamb MW, Grabowski JG, et al. Characteristics of general aviation crashes involving mature male and female pilots. Aviat Space Environ Med 2001;72:447–52.
36. Miura Y, Shoji M, Fukumoto M et al. A 10-year retrospective review of airline transport pilots aged 60 to 63 in Japan. Aviat Space Environ Med 2002;73:485–7.
37. Tsang PS. Assessing cognitive aging in piloting. In: Tsang PS, Vidulich MA, eds. Principles and practices of aviation psychology. Hillsdale, NJ: Lawrence Erlbaum Associates, 2002:507–46.