SHORT COMMUNICATION

Pilot Error in Air Carrier Accidents: Does Age Matter?

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Li G, Grabowski JG, Baker SP, Rebok GW. *Pilot error in air carrier accidents: does age matter?* **Aviat Space Environ Med 2006; 77:737–41.**

Introduction: The relationship between pilot age and safety performance has been the subject of research and controversy since the "Age 60 Rule" became effective in 1960. This study aimed to examine age-related differences in the prevalence and patterns of pilot error in air carrier accidents. ***Methods:*** Investigation reports from the National Transportation Safety Board for accidents involving Part 121 operations in the United States between 1983 and 2002 were reviewed to identify pilot error and other contributing factors. Accident circumstances and the presence and type of pilot error were analyzed in relation to pilot age using Chi-square tests. ***Results:*** Of the 558 air carrier accidents studied, 25% resulted from turbulence, 21% from mechanical failure, 16% from taxiing events, 13% from loss of control at landing or takeoff, and 25% from other causes. Accidents involving older pilots were more likely to be caused by turbulence, whereas accidents involving younger pilots were more likely to be taxiing events. Pilot error was a contributing factor in 34%, 38%, 35%, and 34% of the accidents involving pilots ages 25–34 yr, 35–44 yr, 45–54 yr, and 55–59 yr, respectively ($p = 0.87$). The patterns of pilot error were similar across age groups. Overall, 26% of the pilot errors identified were inattentiveness, 22% flawed decisions, 22% mishandled aircraft kinetics, and 11% poor crew interactions. ***Conclusion:*** The prevalence and patterns of pilot error in air carrier accidents do not seem to change with pilot age. The lack of association between pilot age and error may be due to the "safe worker effect" resulting from the rigorous selection processes and certification standards for professional pilots.

Keywords: aging, aviation, epidemiology, human factors, safety.

FEDERAL AVIATION Regulation 14 CFR 121.383(c) mandates retirement by age 60 for pilots flying Part 121 operations (i.e., air carriers). This policy, commonly known as the "Age 60 Rule," has been the subject of continuing controversy and research since it became effective in 1960. Central to the controversy is the scientific question of whether pilots become less safe as age increases. The research literature on aging and pilot performance has experienced a steady growth in the past two decades, particularly with regard to age-related deficits in cognitive functions and piloting skills and the psychological mechanisms of how age interacts with expertise on pilot performance. There is a general consensus that, despite progressive age-related declines in domain-independent cognitive functions, performance in most flight-related tasks (e.g., tracking, takeoff, and landing) does not differ between older and younger pilots. Among the few flight-related tasks that are found to decline with advancing age are the ability to respond to communication commands (10,12) and time-sharing efficiency (13). Specifically, older pilots tend to be outperformed by their younger counterparts in executing long and quickly spoken air traffic control commands and in multi-tasking under conditions of increased attentional resources. These age-related deficits are due in part to decreased working memory capacity during the process of aging (10,13) and can be compensated for to some degree by flight experience (9,10,13).

Age effects on cognitive functions among pilots have been examined primarily under controlled experimental conditions using flight simulators. It is unclear whether age-related impairments of cognitive functions have any measurable effects on pilots' safety performance in the real world. Although several studies indicate that the risk of accident involvement appears to increase among older pilots (3,5), the empirical evidence is inconclusive because of data limitations and methodological deficiencies. Pilot error is identified as a contributing factor in 85% of general aviation accidents and 68% of commercial aviation accidents (6). Yet little is known about age-related variations in pilot error. In a study of commuter and air taxi pilots (8), we found that the prevalence and patterns of pilot error in aviation accidents remained fairly stable as the pilots aged from their 40s into their 50s. The study findings, however, were limited by the modest sample size (165 accidents) and truncated life span (between age 40 and 60 yr). Extending our previous research on pilot aging and flight safety (2,6,8), this study aimed to answer two questions. First, is the prevalence of pilot error in air carrier accidents associated with pilot age? Secondly, does the type of pilot error in air carrier accidents vary with pilot age?

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This manuscript was received for review in November 2005. It was accepted for publication in March 2006.

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METHODS

This study was part of a larger project aimed at better understanding the effects of aging on safety performance among commercial aviation pilots. The parent project consisted of case series analyses for assessing age-related variations in pilot error and case-control analyses for quantifying the relative risk of accident involvement associated with age. The present study represents a case series analysis of data for air carrier accidents recorded by the National Transportation Safety Board (NTSB) between 1983 and 2002. The NTSB data system is the official repository of investigation reports on all aviation accidents occurring within the United States, including its territories, possessions, and international waters.

The NTSB is an independent Federal agency charged by the U.S. Congress with investigating civil aviation accidents as well as major mishaps in other modes of transportation. NTSB investigations are conducted to determine the probable cause of the accident and to make recommendations for improving safety. The U.S. Federal Government defines an aviation accident as an occurrence associated with the operation of an aircraft in which any person suffers death within 30 d or serious injury, or in which the aircraft is damaged so severely that it requires major repair or replacement of the affected component. Procedures for notifying, investigating, and reporting aviation accidents are prescribed in detail by the Federal Government (4). Data gathered in the investigation are recorded using the standard Factual Report Aviation form (NTSB Form 6120.4) and a set of supplemental forms. The Factual Report Aviation form contains a total of 236 data items, with detailed information about the circumstances, aircraft, and pilot-in-command involved in the accident. Also included in the Factual Report Aviation form is a written narrative describing the facts, conditions, circumstances, probable causes, and contributing factors pertaining to the accident. A cause is defined as a condition that played an essential role in the causation of the accident (i.e., without its presence, the accident would have not occurred), and a factor as a condition that aggravated the development of the accident sequence (i.e., it made the accident more likely or more severe) (11).

Data in the Factual Aviation Report for every air carrier accident occurring between 1983 and 2002 were reviewed by an experienced commercial pilot/flight instructor and aviation safety researcher who served as the project consultant. The project consultant coded the accident type, contributing factors, and pilot errors based on information contained in the NTSB investigation report. In this study, pilot refers to the pilot-in-command, i.e., the crewmember who has the ultimate responsibility for the operational control of the aircraft, and pilot error is operationally defined as any performance factor attributed to the pilot-in-command that was identified either as a probable cause or as a contributing factor for any event in the accident sequence. Excluded from this study were 57 accidents that occurred outside of the United States, 5 that were caused by criminal acts, 37 for which NTSB investigation reports were unavailable at the time when the study was initiated, and 11 in which data on pilot age were missing.

Data coded by the project consultant were merged with computerized data from the NTSB Factual Report Aviation forms and analyzed in relation to age and total flight time of the pilot-in-command at the time of accident. Age was divided into four groups: 25–34 yr, 35–44 yr, 45–54 yr, and 55–59 yr; and total flight time into four groups based on quartiles (1700–8000 h, 8001–11,800 h, 11,801–16,000 h, and 16,001–30,651 h). Group differences in accident circumstances and pilot errors were assessed based on Chi-square tests. Statistical analyses were performed using the Statistical Analysis System software (SAS Institute Inc., Cary, NC).

RESULTS

A total of 558 air carrier accidents were studied. Of the pilots involved, all but two were men. At the time of accident, pilots on average were 46.3 yr (±8.5 SD) of age and had logged 12,117 h of total flight time (± 5703 SD) and 165 h (± 60 SD) in the 90 d preceding the accident.

Pilot Age and Accident Circumstance

Accident circumstances were similar for pilots across different age groups (see **Table A** online*). Overall, 63% of the accidents took place during daytime (7 a.m. to 6 p.m.), 75% on weekdays, 60% at airports, and 81% under visual meteorological conditions. Post-crash fire occurred in 14% of the accidents. Of the 558 pilots involved in the accidents, 5% were fatally injured. The number of engines for the aircraft involved in the accident was the only variable that was significantly associated with pilot age: 11% of the pilots ages 25 to 34 yr were flying aircraft with more than two engines, which increased progressively to 45% for pilots ages 55 to 59 yr ($p < 0.001$) (Table A).

Pilot Age and Accident Type

The type of accidents differed significantly with pilot age (**Table B** online**). Accidents involving older pilots were more likely to be related to turbulence, whereas accidents involving younger pilots were more likely to be taxiing events. For all age groups combined, 25% of the accidents involved turbulence, 21% mechanical failure, 16% taxiing events, 13% loss of control at landing/takeoff, 8% ramp injury, and the remaining 17% involved a host of other conditions (Table B).

Pilot Age and Error

Pilot error was a contributing factor in 34%, 38%, 35%, and 34% of the accidents involving pilots ages 25–34 yr, 35–44 yr, 45–54 yr, and 55–59 yr, respectively ($p = 0.87$). Overall, 35% of the accidents were attributable to pilot error. Patterns of pilot error across different age groups were similar (**Table I**). Of all errors identi-

* Table A can be accessed online at http://www.ingentaconnect.com/content/asma/asem.

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TABLE I. TYPES OF PILOT ERROR IN AIR CARRIER ACCIDENTS BY PILOT AGE, UNITED STATES, 1983–2002.

	Age (yr)				
Type of Pilot Error	25–34 n (%)	35–44 n (%)	45–54 n (%)	55–59 n (%)	Total* n (%)
Inattentiveness	8 (28.6)	14 (20.6)	29 (27.4)	12 (26.7)	63 (25.5)
Did not see and avoid	3 (10.7)	6 (8.8)	8 (7.6)	2 (4.4)	19 (7.7)
Improper preflight planning	1 (3.6)	2 (2.9)	4 (3.8)	2 (4.4)	9 (3.6)
Related to landing gear	2 (7.1)	1 (1.5)	2 (1.9)	0 (0.0)	5 (2.0)
Related to fuel system	1 (3.6)	0 (0.0)	1 (0.9)	1 (2.2)	3 (1.2)
Other	1 (3.6)	5 (7.4)	14 (13.2)	7 (15.6)	27 (10.9)
Flawed decision	5 (17.9)	17 (25.0)	23 (21.7)	10 (22.2)	55 (22.3)
Related to weather	2 (7.1)	7 (10.3)	13 (12.3)	5 (11.1)	27 (10.9)
Flew aircraft with known defect	2 (7.1)	4 (5.9)	3 (2.8)	0 (0.0)	9 (3.6)
Related to engine power loss or shutdown	0 (0.0)	2 (2.9)	1 (0.9)	0 (0.0)	3 (1.2)
Flying low	1 (3.6)	0 (0.0)	0 (0.0)	0 (0.0)	1 (0.4)
Other	0 (0.0)	4 (5.9)	6 (5.7)	5 (11.1)	15 (6.1)
Mishandled aircraft kinetics	4 (14.3)	15 (22.1)	25 (23.6)	10 (22.22)	54 (21.9)
Could not recover from stall	2 (7.1)	1 (1.5)	4 (3.8)	0 (0.0)	7 (2.8)
Poor response to bounce	0 (0.0)	2 (3.0)	2 (1.9)	1 (2.2)	5 (2.0)
Flared too high or improper flare	0 (0.0)	0 (0.0)	3 (2.8)	0 (0.0)	3 (1.2)
Did not use flaps correctly	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)
Other	2 (7.1)	12 (17.7)	16 (15.1)	9 (20.0)	39 (15.8)
Poor crew interaction	6 (21.4)	5 (7.4)	13 (12.3)	3 (6.7)	27 (10.9)
Poor crew coordination	6 (21.4)	5 (7.4)	12 (11.3)	3 (6.7)	26 (10.5)
Other	0 (0.0)	0 (0.0)	1 (0.9)	0 (0.0)	1 (0.4)
Mishandled wind and/or runway conditions	3 (10.7)	8 (11.8)	3 (2.8)	3 (6.7)	17 (6.9)
Poor handling of airport surface wind or turbulence	2 (7.1)	5 (7.4)	2 (1.9)	3 (6.7)	12 (4.9)
Poor response to hazardous runway conditions	1 (3.6)	2 (2.9)	1 (0.9)	0 (0.0)	4 (1.6)
Other	0 (0.0)	1 (1.5)	0 (0.0)	0 (0.0)	1 (0.4)
Improper IFR procedure	0 (0.0)	4 (5.9)	3 (2.8)	1 (2.2)	8 (3.2)
Below minimums anywhere on approach procedure	0 (0.0)	3 (4.4)	1 (0.9)	0 (0.0)	4 (1.6)
Other	0 (0.0)	1 (1.5)	2 (1.9)	1 (2.2)	4 (1.6)
Misjudged conditions or distances while taxiing	1 (3.6)	1 (1.5)	0 (0.0)	0 (0.0)	2 (0.8)
Miscellaneous actions	1 (3.6)	4 (5.9)	10 (9.4)	6 (13.3)	21 (8.5)
Did not use checklist	1 (3.6)	1 (1.5)	4 (3.8)	5 (11.1)	11 (4.5)
Improper engine start procedure	0 (0.0)	0 (0.0)	2 (1.9)	0 (0.0)	2 (0.8)
Lost or unaware of position	0 (0.0)	0 (0.0)	1 (0.9)	0 (0.0)	1 (0.4)
Other	0 (0.0)	3 (4.4)	3 (2.8)	1 (2.2)	7 (2.8)
Total	28 (100.0)	68 (100.0)	106 (100.0)	45 (100.0)	247 (100.0)

*Up to 2 pilot errors per accident were counted; 18 accidents that occurred while the aircraft was under the control of the copilot were excluded. IFR = instrument flight rules.

fied, being inattentive accounted for 26%, followed by flawed decisions (22%), mishandling aircraft kinetics (22%), poor crew interaction (11%), mishandling wind and/or runway conditions (7%), improper instrument flight rules approach (3%), and other (9%).

Pilot Age, Flight Experience, and Error

Data were further analyzed to assess whether the relationship between pilot age and error was confounded by flight experience as measured by total flight time. As expected, older age was associated with increased total flight time (correlation coefficient 0.62, $p < 0.0001$). Total flight time was associated with neither the prevalence ($p = 0.19$) nor the type of pilot error ($p = 0.66$).

DISCUSSION

Based on a thorough review of the research literature, the Civil Aviation Safety Subcommittee of the Aerospace Medical Association (1) concluded that "changes in pilot performance with age are not completely understood, and, therefore, cannot be easily explained." To advance the discourse on the Age 60 Rule, empirical data from rigorously designed epidemiologic studies are especially valuable because they may provide the most relevant evidence for policy evaluation and reform. In this study, we performed an analysis of the relationship between pilot error and age. The results indicate that the prevalence and patterns of pilot error in air carrier accidents are not associated significantly with pilot age. About 35% of air carrier accidents were attributed to pilot error, regardless of pilot age. Inattentiveness, flawed decisions, and mishandling aircraft kinetics together accounted for more than two-thirds (70%) of all pilot errors identified in air carrier accidents. There was little age-related variation in the patterns of pilot error. These findings are generally consistent with our previous study of commuter and air taxi accidents (8). Wiegmann and Shappell (14) analyzed 44 air carrier accidents using the Human Factors Analysis and Classification System and found that "decision errors" accounted for 25% of all pilot errors, which is comparable to our finding that 22% of all pilot errors were flawed decisions (e.g., misjudging weather conditions and terrain).

Why do pilots at different ages make similar errors at similar rates of prevalence in air carrier accidents? We speculate that one of the main reasons might be the safe worker effect (7,8). Air carrier pilots are a highly selected occupational group. In addition to periodical medical examinations that are designed to screen out those physically and mentally unfit, pilots are subject to constant competence tests on the job. Pilots showing deficiencies in flight proficiency and safety performance are likely to be grounded by license termination or other attritional mechanisms (e.g., early retirement and death due to disease or accident). Therefore, pilots who remain on active duty at older ages are likely the safer (and healthier) individuals. These selection mechanisms may have precluded or considerably attenuated the effects of aging on safety performance in professional pilots.

Although pilots across different age groups have similar prevalence and patterns of error, the circumstances of accidents appear to vary with age. Specifically, accidents involving older pilots are more likely to be related to turbulence, whereas a disproportionate percentage of accidents involving younger pilots are taxiing events, such as hitting a moving aircraft or vehicle. The age-related difference in accident circumstances may reflect the differential exposure patterns related to seniority, as older pilots tend to possess greater seniority and fly larger aircraft and longer flights than their younger counterparts. The finding that aircraft flown by older pilots were more likely than those operated by younger pilots to have more than two engines is indicative of the differential exposure patterns among different age groups. Younger pilots fly shorter trips and, therefore, make more landings and takeoffs, exposing them to a greater risk of taxiing mishaps.

It is noteworthy that the lack of age-related variation in the prevalence and patterns of pilot error does not necessarily contradict the findings from previous studies that performance of certain flight-related tasks declines with increasing age. Those studies, conducted in flight simulators under controlled experimental conditions, involved less experienced pilots and used more sensitive outcome measures than the present study. Therefore, the seemingly conflicting results between observational studies and experimental studies are likely caused by the differences in research design and study population.

The prevalence and patterns of pilot error appear to vary greatly with the type of flight operations. Pilot error, particularly mishandled aircraft kinetics, is far more common in general aviation accidents and commuter/air taxi accidents than in air carrier accidents (2,7). It is unclear to what extent the differences in the prevalence and patterns of pilot error across aviation categories are due to differences in pilot flight experience, aircraft, and environments. Because pilot error is associated with both intrinsic (e.g., psychomotor and decision-making skills) and extrinsic (e.g., adverse weather conditions) factors, the differences in pilot error among different aviation categories must be viewed in the context of multivariate interactions.

This study has several limitations. First, the analysis was confined to pilot error identified in accidents. Errors that did not lead to accidents were not captured. It is conceivable that pilot error identified in accidents represents only the tip of the iceberg. In the absence of a surveillance system that encompasses representative samples of all flights, it is impossible to determine the incidence rates and risk factors of pilot error. Therefore, the question of whether the incidence rate (or risk) of pilot error changes with pilot age remains unanswered. Second, this study was based on retrospective data for a 20-yr period. The results could be susceptible to temporal bias and other biases because during the study period aviation experienced profound changes in regulations, aircraft, technologies, and pilot training. These changes may affect different cohorts of pilots in different ways, and thus confound the relationship between pilot age and error as examined in this study. Finally, this study relied solely on NTSB data. The NTSB uses a matrix of sequence-of-events by probable causes/contributing factors to delineate the causal chains of a given accident. Investigations of human factors are concentrated primarily on pilot performance. Information about the role of organizational factors, such as company safety culture and supervisory practice, is not adequately collected. It is worth noting that pilot error examined in this study constitutes only one element of human factors.

Despite the limitations, this study provides valuable empirical data for understanding the relationship between pilot age and safety performance. Results from this study indicate that the prevalence and patterns of pilot error identified in air carrier accidents are independent of pilot age. The lack of age-related variations in pilot error may be due to the safe worker effect resulting from the rigorous selection processes and certification standards for professional pilots. Future research should examine the effects of aging on the risk of pilot error and accident risk using prospectively collected data.

ACKNOWLEDGMENTS

This research was funded by Grant R01AG13642 from the National Institute on Aging, National Institutes of Health. Preparation of this manuscript was supported in part by a fellowship grant from the John Simon Guggenheim Memorial Foundation to Dr. Li. The authors thank Margaret W. Lamb of Sunshine Aviation Safety Studies for reviewing and coding the accident reports, and Yandong Qiang, M.D., M.P.H., M.H.S., for statistical assistance.

REFERENCES

1. Aerospace Medical Association, Aviation Safety Committee, Civil Aviation Safety Subcommittee. The age 60 rule. Aviat Space Environ Med 2004; 75:708–15.
2. 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.
3. Broach D, Joseph KM, Schroeder DJ. Pilot age and accident rates report 3: an analysis of professional air transport pilot accident rates by age. Oklahoma City, OK: FAA Civil Aeromedical Institute, Federal Aviation Administration; 2000.
4. Federal Aviation Administration. Aircraft accident and incident notification, investigation, and reporting. Washington, DC: Federal Aviation Administration; 2000.
5. 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.
6. Li G, Baker SP, Grabowski JG, et al. Factors associated with pilot

error in aviation crashes. Aviat Space Environ Med 2001; 72: 52–8.
7. Li G, Baker SP, Grabowski JG, et al. Age, flight experience, and risk of crash involvement in a cohort of professional pilots. Am J Epidemiol 2003; 157:874–80.
8. Li G, Baker SP, Lamb MW, et al. Human factors in aviation crashes involving older pilots. Aviat Space Environ Med 2002; 73:134–8.
9. 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.
10. Morrow DG, Yesavage J, Leirer V, Tinklenberg J. Influence of aging and practice on piloting tasks. Exp Aging Res 1993; 19:53–70.
11. National Transportation Safety Board. NTSB aviation coding manual. Washington, DC: National Transportation Safety Board; 1998.
12. Taylor JL, Yesavage JA, 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.
13. Tsang PS. Assessing cognitive aging in piloting. In: Tsang PS, Vidulich MA, eds. Principles and practices of psychology. Hillsdale, NJ: Erlbaum; 2002:507–46.
14. Wiegmann DA, Shappell SA. Human error analysis of commercial aviation accidents: application of the Human Factors Analysis and Classification System (HFACS). Aviat Space Environ Med 2001; 72:1006–16.