Age and Expertise Effects in Aviation Decision Making and Flight Control in a Flight Simulator

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Abstract

Introduction—Age (due to declines in cognitive abilities necessary for navigation) and level of aviation expertise are two factors that may affect aviation performance and decision making under adverse weather conditions. We examined the roles of age, expertise, and their relationship on aviation decision making and flight control performance during a flight simulator task.

Methods—Seventy-two IFR-rated general aviators, aged 19–79 yr, made multiple approach, holding pattern entry, and landing decisions while navigating under Instrument Flight Rules weather conditions. Over three trials in which the fog level varied, subjects decided whether or not to land the aircraft. They also completed two holding pattern entries. Subjects' flight control during approaches and holding patterns was measured.

Results—Older pilots (41+ yr) were more likely than younger pilots to land when visibility was inadequate (older pilots' mean false alarm rate: 0.44 vs 0.25). They also showed less precise flight control for components of the approach, performing 0.16 SD below mean approach scores. Expertise attenuated an age-related decline in flight control during holding patterns: older IFR/CFI performed 0.73 SD below mean score; younger IFR/CFI, younger CFII/ATP, older CFII/ATP: 0.32, 0.26, 0.03 SD above mean score. Additionally, pilots with faster processing speed (by median split) had a higher mean landing decision false alarm rate (0.42 vs 0.28), yet performed 0.14 SD above the mean approach control score.

Conclusions—Results have implications regarding specialized training for older pilots and for understanding processes involved in older adults' real world decision making and performance.

Keywords

age; expertise; weather-related aviation skills

Navigating aircraft is a complex, time-pressured activity, influenced by individual difference factors such as level of expertise and cognitive abilities. For older aviators, who typically experience age-related declines in cognitive abilities and visual acuity, these factors may play an even greater role during adverse weather conditions. Although many studies have investigated factors associated with weather-related aviation incidents (26), to our knowledge, no study to date has experimentally examined the relationship between two key factors associated with decisional error in aviation incidents: age and flight expertise. The purpose of this study was to investigate the effects of age and flight expertise on a flight simulator test.

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During the test younger and older general aviators had to make decisions about landing and entering holding patterns while accomplishing precise flight control in foggy weather conditions.

Flight simulator performance is an ideal method for assessing the roles of age and expertise on aviation decision making. Previous work on factors associated with pilot error in Instrument Flight Rules (IFR) weather conditions (allowing a pilot to fly in poorer visibility conditions using navigational instruments) typically were based on epidemiological studies. These studies could not control for variability in environmental and individual difference factors that affect aviation decision making (11), such as severity of weather, flight duration, the point in the flight at which the pilot error occurred, and type of aircraft. The use of a flight simulator provides control over such factors. Additionally, flight simulator performance allows pilots to use their domain-relevant declarative and procedural memory in a more realistic fashion than do typical paper and pencil assessments (21,25). To our knowledge, only one flight simulator study investigated performance in adverse weather conditions, but that study did not examine age effects (25).

Although there is ample literature on the general area of aging and decision making [for a review, see Peters et al. (17)], aircraft navigation and decision making places specific demands on the older aviator due to the combination of time-pressure, safety concerns, and attentional demands. When older aviators make a poor decision, it may be due in part to age-related declines in cognitive abilities crucial for aircraft navigation, such as information processing speed, working memory, and attention, especially in the face of interference or distraction. For example, age-related decline in execution of air traffic control (ATC) commands may occur in large part because of age differences in working memory, which in turn appears to be mediated by decreases in both processing speed and cognitive control (23). Furthermore, pilots over 60 yr of age on average perform worse on dual tasking tests than younger pilots, especially when the task requires high attention and precise control (24). Finally, age is negatively associated with many measures of the Cogscreen AE battery, a cognitive battery assessment specifically designed to measure cognitive skills related to aircraft navigation (10). As a whole, findings suggest that older pilots may make poorer aviation decisions—particularly in situations that require high levels of divided attention and processing speed—because of age-related changes in cognitive abilities and strategies. These findings take on real world relevance as the percentage of older general aviators has increased considerably in recent years (14).

Numerous studies have differentiated decision making processes and skills between expert and novice pilots. Expert pilots are more likely to use flexible task management during emergencies and procedural task management during routine flying. They also switch attention more frequently, more efficiently seek out pertinent information and make decisions, and perform higher priority activities earlier than less expert pilots (26). In contrast, novice pilots do not realize that they need to start the decision making process in the first place and, when seeking out information, do not appear to know which information is most relevant (26). Expert pilots are more knowledgeable and adept than less expert pilots at using relationships between different information that require a complex interplay of working memory and attention, such as the use of the relationship between speed and direction of visual information to anticipate the ideal flight path (16). Thus, this literature consistently indicates an expertise advantage for decision making and flight control in a range of aviation tasks.

The specialized knowledge and perceptual-motor skills acquired by experts through years of training and experience may compensate for age-related declines in cognitive abilities associated with the particular domain (20). Aviation expertise should attenuate age-related declines in aircraft navigation and decision making, even though, as noted above, basic cognitive abilities that decline with age, such as processing speed, are required for aircraft

navigation. In other words, older expert pilots should be able to utilize their accrued aviation knowledge and procedural skills to maintain flight control performance and quality of aviation decisions (3). In contrast, their less expert counterparts should be more likely to show age-related declines in flight performance. This idea has gained support from studies investigating a variety of skilled domains that tap perceptual motor skills (as in typing or piano playing), choosing the best course of action (as in chess or the game of GO), or timesharing during simulated flight [as reviewed in Taylor et al. (22)].

Support for expertise attenuation of age-related differences in the area of aviation has been found. Expertise ameliorated age-related declines in read back accuracy and dual tasking (12,13,24). These studies, however, were based on paper-and-pencil or PC-type tests, and typically defined expertise level as having any versus no prior aviation experience. Support is more elusive when pilots are assessed in more naturalistic settings, such as in a flight simulator, when pilots at different levels of expertise are compared, and when the aviation task is strongly dependent on working memory and speed of processing (13,22,23). Thus, when examining age and expertise level effects in flight simulator performance, we expect that expertise will be more likely to aid older expert pilots' performance on perceptual-motor tasks and tasks that are relatively unconstrained by time.

Prior aviation studies that investigated decision making involving adverse weather conditions did not examine age in the analyses (27), had a confound between age and expertise (defined as total number of flight hours), or did not test the interaction between age and expertise (although main effects of age and expertise were found in the expected directions) (15). Thus, very little is known about how age and expertise may interact to affect aviation decision making in adverse weather conditions.

The purpose of the present study was to elucidate the roles of age and expertise in aviation decision making while navigating aircraft under Instrument Meteorological Conditions (IMC) (weather conditions that generally require pilots to fly primarily by reference to instruments, such as cloudy weather). Based on work by Ericcson and colleagues (4), level of expertise was defined by Federal Aviation Administration (FAA) ratings, in which higher ratings require additional hours of training and deliberate practice to advance skills. We examined two types of common aviation decisions. One decision was whether or not to land in fog. The second decision was determining the correct entry into the holding pattern (based on ATC-assigned radials), a race track shaped maneuver designed to delay an aircraft which is already in flight and keep it in specified, and therefore safe, airspace. We also examined flight control during Instrument Landing System (ILS) approaches to the runway and holding patterns, which require visual monitoring and psychomotor skills that then may influence decision making. We made the following hypotheses for each type of flight activity:

1. Main effects for age and expertise will be found, such that younger pilots and more expert pilots will make more accurate holding pattern entry and landing decisions and have better flight control than older pilots and less expert pilots.

2. Age × expertise interactions will be found, such that expertise aids older pilots' accuracy of holding pattern entry and landing decisions and flight control.

METHOD

Subjects

There were 72 pilots, 19 to 79 yr of age, with two levels of IFR expertise who completed the study. Moderate expertise was defined as having a rating of IFR (instrument rated, allowing a pilot to fly in poorer visibility conditions using navigational instruments) or CFI (certified flight instructor). High expertise was defined as having a rating of CFII (certified flight

instructor of IFR students) or ATP (eligible to fly air-transport planes). The study was designed such that half the subjects were less than 40 yr of age; among these younger pilots, one half had moderate levels of expertise. Among the older pilots (40 yr and older), one half also had moderate levels of expertise. There were no significant age differences between younger IFR and CFII/ATP groups and between older IFR and CFII/ATP groups. To be eligible to participate in the study, pilots had to be IFR-rated with a current FAA Medical Certificate (Class III or higher), which entails an assessment of pilots' vision, hearing, and physical and mental health. Subjects' medical certificates were verified. No special neurological, visual acuity, sleep disorder or hearing tests were performed. Subjects were recruited from flyers posted at local airports and from pilot gatherings. The study was approved by the Stanford University Institutional Review Board. All subjects gave written informed consent to participate, with the right to withdraw at any time. Mean years of school education was 16.67 yr (*SD* = 2.27) with a range of 12–23 yr. Mean total flight hours was 3029.23 h (*SD* = 4109 h, range: 241–23,025 h), and mean number of flight hours in the month prior to study participation was 24.79 h (*SD* = 30.96 h, range: 0–201 h). Of the 72 pilots, 71 were male, and 65 were Caucasian, non-Hispanic. There were 37 pilots who had careers associated with aviation. Of the 36 IFR/CFI recreational pilots, 4 held aviation-related careers such as aerospace engineer and fueler, 2 were flight instructors, and 2 had jobs that entailed aircraft piloting. Of the 36 CFII/ATP pilots, 17 were flight instructors, 11 pilots, and 1 retired NASA engineer. No subject experienced simulator sickness or dropped out from the protocol during testing. Table I describes demographic and cognitive ability characteristics of the subjects.

Equipment

Pilots "flew" in a Frasca 141 flight simulator (Urbana, IL). Motion, vibration, and sound elements were not incorporated into this simulator protocol. The simulator was linked to a computer specialized for graphics (Dell Precision Workstation and custom C++ OpenGL Linux software) that generated a "through-the-window" visual environment and continuously collected data concerning the aircraft's position and communication frequencies. The software also collected quantified flight data regarding the accuracy of the Land/No Land and execution into the holding pattern decisions. The simulator is located in a quiet, darkened room kept at a comfortable temperature with the cockpit independently lit from the projector display. The display is projected on a screen 15 ft (4.57 m) in front of the pilot. The simulation occurred during normal working hours from 0900 to 1600 at the pilot's preference. Previous work in our lab indicates that the flight simulator has validity as it distinguishes performance between novice and expert aviators, and between younger and older aviators (22,23).

Procedure

Subjects first signed the consent form and provided demographic information. A research assistant, who is an IFR-rated pilot, read the following preflight instructions to subjects: "Today we will be flying three ILS's and two different holding patterns. To do this, you will fly your ILS to a touch and go or a missed approach and then you will enter a holding pattern. Takeoff and climb at 100 kn on runway heading, 303° to 1200 ft. At level off set your power (20 in of manifold pressure) to maintain 100 kn, do not adjust the prop or mixture. You will fly two times around the holding pattern and then will exit on a 300° heading at 1200 ft indicating 100 kn. I will reposition you to a 6 mi final and you will fly your second ILS and then hold for two times around the holding pattern and then exit the same as in the first hold. I will once again pre-position you on a 6 mi final for your last approach which can end as a full stop or a go-around. In the case of a go-around I will end the session in flight.

"All approaches will be the ILS to 30 at SJC (ISJC, 110.9, 303 in the OBS) with a 200′ DH (200′ AGL). All missed approaches will be on the TFD VOR (117.4) and the initial procedure

is to climb to 1200′ at 100 kn on the 123 radial with the OBS set to 303. Expect further clearance instructions in 2 min."

Next, subjects flew the simulator for 10 min at 100 kn and completed two approaches to the runway under conditions of clear skies to become more familiar with the simulator. They then completed the experimental simulator scenario, in which they flew under Instrument Meteorological Conditions for approximately 1 h.

Two variations of fog density were presented during the flight simulator scenario, in which subjects flew three ILS approaches to the runway, each time making a "Land/No Land" decision upon reaching an altitude of 200 ft (~70 m) above ground, called the decision height. In one variation of fog density, although fog is present, the runway and other markers (VASI lights, "30" numbers) are visible at the decision height, and thus should lead to the decision to land. In the other variation, the fog is too thick to see the runway or other Federal Air Regulation Section 91.175 legally acceptable markers at the decision height. Such visibility should lead to the decision to not land, though other aspects of the airport environment were visible. Across the three trials, subjects within each age by expertise group were randomly assigned to complete one of two sequences of fog density variation: 1) Land, Land, No Land; or 2) Land, No Land, Land. Thus, subjects should land in two out of the three trials. These two sequences were chosen in an attempt to control for order effects in a relatively small sample while keeping participant burden down. After the first and second approaches (to Runway 30 with a heading of 303°), subjects entered a holding pattern assigned by the research assistant, who acted as air-traffic control. Based on the holding pattern assigned (273°, 283°, 323°, or 333° radial), subjects should make either a parallel or tear-drop entry into the holding pattern. In a parallel entry, the pilot flies to the holding fix, parallels the inbound course for 1 min outbound, then turns back, flies directly to the fix, and continues in the hold. In a teardrop entry, the pilot flies to the holding fix, turns into the protected area, flies for 1 min, then turns back inbound, proceeds to the fix, and continues in the hold.

Entry into the holding pattern was counter-balanced with the following orders 1): teardrop entry followed by parallel entry; or 2) parallel entry followed by teardrop entry. Subjects then completed a battery of cognitive tests designed to assess abilities pertinent to navigating aircraft [CogScreen AE battery (9)] (Table I), as well as a few general questions about their experience in the flight simulator.

Data Reduction and Statistical Analyses

The main outcome measure for the Land/No Land decision was adjusted hits. A hit was defined as landing during the Land condition, whereas a false alarm was defined as landing during the No Land condition. The number of hits was adjusted because we had two Land trials and only one No Land trial. We used the following formula to calculate adjusted hits: mean number of hits - false alarm. Thus, the adjusted hits scores range from −1 (0 hits, 1 false alarm) to 1 (2 hits, no false alarm).

To take into account the difference between performing an inaccurate holding pattern entry versus completely missing the hold pattern entry, we quantified execution accuracy of the holding pattern entry with the following values: 1 (Correct Entry), 0.5 (Other Entry), 0 (Missed Entry). Thus, across the two holds, the range of scores is 0 to 2. Finally, indices of sensitivity and response bias, d' and c, were calculated across Trials 2 and 3 of the landing decision task (Trial 1 for all subjects was a land scenario, in which false alarms can't be calculated).

Several steps were taken to reduce the 36 individual flight control variables into standardized composite variables. Two sets of principal components analyses were conducted. First, principal components analyses within each trial revealed three approach and three holding

pattern composite variables. Spearman's rank correlations indicated that all composite variables were significantly correlated across trials, e.g., the lateral deviations composite variable in trial 1 was correlated to the lateral deviations composite variable in trials 2 and 3 (Spearman's rank values ranged from 0.32 to 0.68, all p's < 0.05). Therefore, we used the means of each individual variable across trials in the second principal components analyses to derive the final set of composite variables. Finally, because the flight control variables consist of different units, all individual variables were transformed into z-scores. Thus, composite variables used in hypothesis testing consist of standardized data. Principal components analyses revealed the following composite variables for flight control:

Approach composite variables—1) lateral deviations; 2) aileron movements; and 3) elevator movements—Small lateral deviations indicate the ability to maintain parallel alignment with the runway, which in turn facilitates control of the aircraft's altitude. Ailerons control movement on the aircraft's longitudinal axis, i.e., rolling, whereas elevators control the vertical direction of the aircraft nose, i.e., traveling upwards or downwards. Based on navigational logistics, lateral deviations is considered to be the main approach measure, with ailerons and elevators as secondary measures. For all approach measures, positive scores indicate greater deviations from the ideal, and thus worse flight control. As would be expected, Spearman's rank correlation indicated that ailerons and elevators were significantly correlated with lateral deviations (ailerons: $r_s = 0.45$, $P < 0.001$; elevators: $r_s = 0.33$, $P = 0.004$).

Holding pattern composite variables—deviations from 1) assigned altitude; 2) bank angle; and 3) ideal speed—Bank angle measures the amount of tilt (in degrees) that occurs during the turns of the holding pattern, typically 25°. We also included an additional composite variable, overall deviations, defined as the combination of lateral and vertical deviations from the ideal pattern. Overall deviation is the main measure of performance during the holding pattern. For all holding pattern measures, positive scores indicate greater deviations from the ideal, and thus worse flight control. As would be expected, bank angle and altitude deviations were strongly correlated ($r_s = 0.72$, $P < 0.001$), and bank angle was correlated with overall deviations ($r_s = 0.36$, $P = 0.002$).

For all analyses, the predictor variables were age, expertise, and age × expertise. Age was coded as a continuous variable centered at the median age (40.5 yrs) and expertise as an ordinal variable ($−0.5$ for IFR/CFI, 0.5 for CFII/ATP). The age × expertise interaction was calculated by multiplying each participant's age by coded level of expertise. For the Land/No Land decision and execution accuracy of the holding pattern entry, PROC GENMOD in SAS was used. For the flight control measures, PROC GLM was utilized.

RESULTS

Demographics

Age was positively correlated with education ($r_s = 0.34$, $P = 0.004$) and associated with poorer performance on four of six cognitive measures (selected from CogScreen-AE): Dual task—Tracking error ($r_s = 0.53$, $P < 0.001$); Dual task—Boundary hits ($r_s = 0.45$, $P < 0.0001$); Shifting Attention Instruction throughput ($r_s = −0.29$, $P = 0.016$); and Symbol Digit Coding throughput ($r_s = −0.45$, $P < 0.001$). Level of expertise was not significantly associated with performance on any of the cognitive measures. GLMs indicated increased total flight hours with age ($b = 115.00$, $SE(b) = 25.46$, $P < 0.0001$), expertise rating ($b = 3163.03$, $SE(b) = 728.13$, $P < 0.0001$), and a significant age × expertise interaction ($b = 168.34$, $SE(b) = 50.91$, $P < 0.01$), in which older CFII/ATP pilots had the most flight hours. Higher expertise rating was associated with greater number of flight hours in the past month ($b = 28.46$, $SE(b) = 6.76$, $P < 0.0001$) (Table I).

Aviation Landing and Holding Pattern Execution Decisions

Preliminary analyses revealed a mean overall accuracy rate of 63.04% (SD = 5.69%) for the landing decision and 72.92% (SD = 5.24%) for the holding pattern entry decision, indicating that subjects' decisions were above chance, yet not at ceiling on these tasks. Modest sensitivity in distinguishing between fog conditions ($d' = 1.2$), and a response bias toward the more conservative decision to not land ($c = 0.24$) were found. On Likert scales from 1 (not at all) to 7 (a great deal), subjects rated the landing decision and holding pattern execution tasks to be moderately challenging [landing decision mean = 4.85(1.07); holding pattern mean = 4.71 (1.04) and similar to actual ILS approaches and holds—ILS approach mean = 4.36(1.36), holding pattern mean = 4.57(1.36)]. In addition, a significant sequence effect on landing decision was found. Pilots who completed the Land, No Land, Land sequence made more accurate decisions across the three trials than pilots who completed the Land, Land, No Land sequence ($\chi^2 (2) = 11.85$, $P = 0.003$). Importantly, no sequence or age by expertise group difference was found in the first trial, in which all subjects had a Land scenario (Land, Land, No Land hit rate: 61.77%; Land, No Land, Land hit rate: 65.79%). Therefore, sequence was added as a predictor to the model of landing decision accuracy. Two variables were significant predictors of adjusted hits: sequence ($b = -0.34$, $SE(b) = 0.11$, $P = 0.002$), and age ($b = -0.009$, $SE(b) = 0.004$, $P = 0.019$, effect size (ES) $= -0.27$). Pilots who had the Land, Land, No Land sequence had adjusted hits 0.34 lower than those pilots who had the Land, No Land, Land sequence. With every additional year of age, the number of adjusted hits decreased by 0.009. This finding is driven by an age-related inclination to land when visibility was inadequate (i.e., false alarms) ($b = 0.008$, $SE(b) = 0.004$, $P = 0.036$, ES $= -0.25$). Consistent with this result, age was associated with a less conservative response bias (younger pilots: $c = 0.335$, older pilots: $c = 0.165$). Table II depicts group means and SD for Land/No Land decision variables. Note that for ease of exposition, age is tabulated as two groups (under 40 and 40+).

Execution accuracy of the holding pattern entry was not significantly predicted by age, expertise, or age $\times$ expertise, (p's . 0.14). See Table II for means and SD by age $\times$ expertise group.

Flight Control During the Approach and Holding Patterns

Age and expertise predicted two aspects of the approach maneuver. During the approach maneuver, age was associated with greater deviations in ailerons (ES = 0.24), which are used to roll the aircraft along its longitudinal axis. Thus, age was associated with poorer performance on this approach measure. In contrast, increased expertise was associated with less deviation in lateral positioning during the descent (ES = −0.30), indicating closer performance to the ideal approach altitude pattern.

For the amount of banking during the holding patterns, age (ES = 0.42) and the age $\times$ expertise interaction (ES = −0.30) were significant predictors. As hypothesized, age was associated with poorer banking (greater deviations from the ideal). Duncan's multiple range test revealed that the age $\times$ expertise interaction was driven by the older IFR/CFI pilots performing significantly worse than the younger pilots and the older CFII/ATP pilots (Fig. 1). Table III depicts the parameter estimates for age, expertise, and the age $\times$ expertise interaction for each of the flight control measures. In summary, the flight control results suggest an age-related decline in some aspects of flight control, but in the case of banking, this decline is attenuated by expertise.[*]

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[*]Analyses were conducted again, replacing FAA rated levels of expertise with recent flight experience (number of flight hours in the previous month). A similar pattern of results as those reported was found with two exceptions. For lateral deviations during the approach, recent flight experience was not a significant predictor, and for bank deviations during the holding pattern, the age $\times$ recent flight experience interaction was not significant. Importantly, the age effects remained the same as those reported.

Secondary analyses—Secondary analyses, which included measures of cognitive ability in the model and correlations between flight control and decision making, were conducted. Several measures of cognitive ability were negatively correlated with age. Because cognitive ability measures may provide indices of "functional age" (20), we created two standardized composite variables of cognitive ability and added them to the models in which age predicted decision accuracy and flight control. One cognitive variable assessed visual-motor tracking errors (dual task tracking error and dual task boundary hits); the other assessed speed of processing (pathfinder throughput and symbol digit throughput). There was a modest negative correlation between the two composites ($r_s = -0.35$, $P = 0.003$). We then reran analyses, but this time entering the two cognitive variables first into the model. Results for the landing decision and banking performance during the holding pattern remained the same or strengthened after including these cognitive variables in the model. (Landing decision: age b = -0.012, SE (b) = 0.004, $P = 0.005$, ES = -0.34; holding pattern bank deviation: age $b = 0.029$, SE (b) = 0.008, $P = 0.001$, ES = 0.44; age × expertise $b = -0.039$, SE (b) = 0.015, $P = 0.012$, ES = -0.31). However, the aileron performance results changed such that age was no longer a significant predictor ($P = 0.27$), but expertise and the speed of processing variable became significant. For expertise, the slope (b) was -0.47 (SE (b) = 0.21, $P = 0.044$, ES = -0.27), whereas for the speed of processing variable, the slope was -0.28 (SE (b) = 0.13, $P = 0.036$, ES = -0.26). Speed of processing also was a significant predictor of landing decision (adjusted hits: $b = -0.150$, SE (b) = 0.685, $P = 0.029$, ES = -0.26), such that with slower speed of processing, landing decisions were more accurate. Further investigation revealed a trend toward a negative correlation between adjusted hits and speed of processing among the older pilots ($r_s = -0.27$, $P = 0.11$), but no correlation among the younger pilots ($r_s = -0.17$, $P = 0.32$). In summary, smaller aileron oscillations were associated with faster speed of processing and increased expertise. More accurate landing decisions were associated with slower speed and younger age.

To explore whether a global decision, such as whether or not to land, was associated with flight control, we conducted two sets of correlations. In the first, we correlated the approach performance measures with the landing decision variables. A significant correlation was found between elevators and mean misses (Spearman's $r = 0.61$, $P < 0.001$). That is, pilots with more gross elevator movements during the approach and descent to the runway tended to avoid landing. In the second set of correlations, we correlated execution accuracy of the holding pattern entry with holding pattern flight control measures. A negative association between holding pattern entry execution accuracy and overall deviations was found ($r_s = -0.34$, $P = 0.006$). Thus, as entry accuracy increased, overall deviations decreased during the holding pattern.

DISCUSSION

We did not find support for our hypotheses regarding execution accuracy of the holding pattern entry. Neither age nor expertise predicted performance. However, compared to younger pilots, older pilots made less accurate Land/No Land decisions. In particular, older pilots were more likely to land under conditions in which it was too foggy to see the runway. This result was strengthened when a speed-of-processing measure was included in the model. Of the two landing decision errors, incorrectly landing can have dangerous consequences for the pilot and possibly others, whereas incorrectly missing can be viewed as a more conservative approach. The pattern of age differences in making landing decisions may be an artifact from using a flight simulator rather than actual flight; however, previous work in our laboratory has indicated that the simulator is a valid measure of aviation performance (22,23). Other possible reasons include poorer vision and increased tendency of strategy error.

As revealed by the sensitivity indices, d', older pilots may have had greater difficulty seeing the runway at decision height due to poorer vision. Several aspects of vision decline with age, such as acuity, contrast sensitivity, retinal illumination, accommodation of the lens, increased susceptibility to glare, and peripheral field loss (8). Corresponding to these physiological changes, age is significantly correlated with visual impairment and declines in visual attention, memory, organization, discrimination, search efficiency, divided and selective attention, and the ability to adapt to the complexity of visual processing-motor output (8). Thus, although general aviators' vision is checked during their medical screening and FAA medical certification requires vision of at least 20/40 in each eye (with or without correction), it may be that these visual decrements are too subtle to be corrected by glasses or contact lenses, but do impact aviation decision making. This suggestion is supported by the finding that age-related increases in hazard perception response time appear to be largely explained by two vision-based measures, contrast sensitivity and useful field of view (9).

The result also is consistent with research demonstrating age differences in the decision making process based on changes in cognitive ability (17). Including cognitive measures into the model affected the predictive strength of age in explaining some aspects of flight navigation. One interpretation of the results is that the flight measures can be seen as tasks of divided attention. The negative correlation found between performance on the dual task cognitive measures and age suggests that age-related differences may be due to decrements in attention rather than decision making per se. However, the dual task cognitive measures did not significantly predict flight performance. Only speed of processing performance accounted for the age-related differences in aileron control. The results indicate that age-related declines in cognitive ability may affect certain aspects of flying an aircraft. Indeed, recent research suggests a complex relationship between age, cognition, and vision, in which a composite measure of cognition mediated age-related declines in useful field of view (5). This research, however, was based on a computer-based task. Research that incorporates eyetracking during flight simulator performance with neuropsychological and vision assessment is required to further investigate this interaction in a real-life setting (19).

Our hypothesis regarding better decisions with increased expertise was not supported, possibly due to methodological reasons. Our range of expertise may have been too limited to detect expertise differences. Other studies that found expertise effects in flight simulator performance included VFR pilots as the least expert group (22,23). A VFR rating allows a pilot to fly under visual flight rules only, which limits them to flying only in good weather conditions and consequently excludes them from participating in our study. Studies that do find expertise differences in the flight simulator find that the differences are driven by attention to cues (21). It may be that our scenarios did not produce adequately realistic visual cues related to weather to detect expertise differences (21). However, the sensitivity index score suggests that visual cues were adequate. Alternatively, lack of expertise effects on the decision making tasks suggests that psychological factors, such as risk perception and overconfidence, may play a larger role in this type of decision. In other words, the pilots may have been over confident in their ability to land with some airport environment, but not the legally required, runway environment, in view. Future studies that include a wider range of expertise, as well as the inclusion of psychological factors associated with decision making will shed more light on this issue.

We found some support for our hypothesis regarding flight control. Older pilots showed evidence of over-controlling the 'aircraft' by oscillating more on their ailerons during the approach. When cognitive measures were included in the model, however, age no longer explained aileron performance. Instead, level of expertise and speed of processing emerged as significant predictors, such that higher levels of expertise and faster processing speed were associated with better performance.

Older pilots also oscillated more during banking while performing the holding pattern than younger pilots. However, expertise compensated for the age-related increase in bank deviations. Older IFR/CFI pilots showed significantly greater fluctuations in flight control while banking than the other three groups. These results are consistent with previous work, in which older pilots performed significantly worse than younger pilots on measures of ATC communication execution, traffic avoidance, emergencies, and approach (22,23). Yet in these studies, no age × expertise effect was found, possibly because of sampling differences or because they did not measure holding pattern performance. Holding patterns are more challenging than other aspects of flight navigation, such as the approach, and consequently provide more of an opportunity for subtle differences to emerge.

Consistent with other work, expertise was associated with more steady control of the primary measure of approach, lateral deviations (22). Thus, even in this sample of experienced IFR-rated pilots, expertise effects were detected. Consistent with other flight simulation work, results indicate that pilot error occurs in flight simulation, and that age and expertise effects can be detected. That expertise and speed of processing ameliorated age-related differences in performance indicates that older pilots' flight control skills have the potential to be improved with deliberate practice. This finding has theoretical and practical implications. In the field of cognitive aging, substantial evidence indicates that healthy older adults can benefit from training in basic cognitive skills; in some cases, skill improvements can be transferred to other domain relevant tasks [for a review, see Hertzog et al. (7)]. Most of these studies have focused on laboratory tasks. Very few studies have investigated the effects of cognitive training on older adults' skills in real-life situations, particularly those in which decisions can have serious consequences (7). One such study conducted two types of training— speed of processing and driving simulation training. Both types of training led to improvements in older adults' road driving; however, effects of speed of processing training were better maintained 18 mo later (18). Our findings suggest that providing older pilots with focused training in the flight simulator for situations that can carry a high degree of risk in real life, coupled with speed of processing training may be an ideal way to improve older aviators' flight safety.

The practical implications of the findings are important, given that weather-related accidents have the highest rates of fatality (71%) among general aviation accidents (1). Additionally, pilot error is the probable cause in 75–85% of general aviation crashes, and decisional error causes more accidents than procedural or perceptual-motor errors (6). These statistics are especially pertinent for older pilots, as the percentage of older general aviators has increased considerably in recent years (14). It therefore is of great importance to understand which factors affect decisional error in weather-related general aviation incidents and ways in which these errors can be prevented.

In this study, we investigated the effects of age and expertise on common aviation decision making tasks. Age was associated with poorer accuracy in determining whether or not to land under poor visibility conditions, but not with execution accuracy of the holding pattern entry. The inconsistent findings may be due to the greater level of difficulty in the landing decision than in the holding pattern entry decision. Surprisingly, expertise was not associated with either general aviation decision making task. Measures of flight control indicated that older pilots tended to overcontrol the plane during the holding pattern. However, expertise attenuated for the age-related decrease in flight control during the holding pattern. Expertise also was associated with better flight control during the approach. Results have implications for better understanding cognitive processes associated with older adults' decision making and performance, and for specialized aviation training for older pilots.

Acknowledgments

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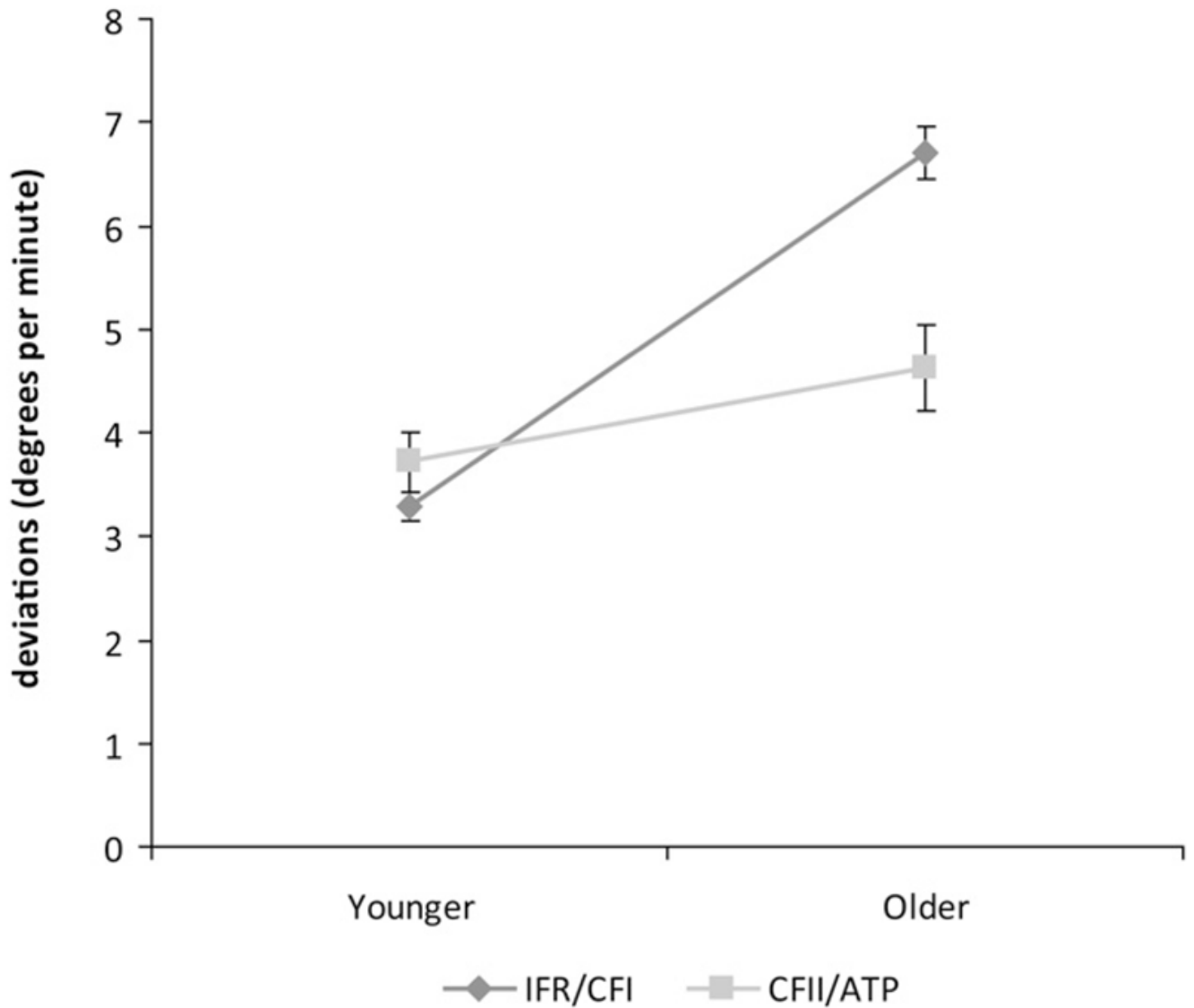
Fig. 1.
Relationship between age and expertise level on deviations from the ideal holding pattern bank performance. Error bars represent SE. Higher scores indicate greater deviations, and thus, worse performance.

TABLE I

DEMOGRAPHICS AND COGNITIVE ABILITY CHARACTERISTICS BY AGE AND EXPERTISE GROUP; MEAN (SD).

	Younger IFR/CFI	Younger CFII/ATP	Older IFR/CFI	Older CFII/ATP
n	18	18	18	18
Age and range (yr) [†]	30.00 (6.42) (19 – 39)	32.61 (5.41) (22 – 39)	54.1 (6.46) (42 – 63)	56.50 (10.33) (42 – 79)
Education (yr)	16.78 (2.37)	15.78 (1.73)	17.11 (2.30)	17.00 (2.54)
% male	100	94.44	100	100
% Caucasian, non-Hispanic	83.33	94.44	83.33	100
Total log hours	667.72 (563.39)	2653.59 (2371.48)	1468.78 (1101.09)	7326.83 (5931.19)
No. flight h past month	12.41 (8.90)	43.23 (32.47)	10.85 (7.71)	32.66 (44.89)
No. IFR flight h past 90 d	2.18 (2.07)	4.9 (6.86)	3.33 (5.32)	1.79 (2.54)
Cognitive Measures:				
Dual Task: Tracking Error	36.17 (21.40)	42.91 (27.99)	61.65 (26.72)	68.67 (23.58)
Dual Task: Boundary Hits	0.77 (1.25)	2.29 (2.97)	3.29 (4.20)	3.50 (3.17)
Manikin Throughput	34.61 (6.80)	32.61 (6.96)	33.22 (8.34)	32.44 (10.79)
Pathfinder Combined Throughput	60.61 (15.86)	53.89 (16.27)	56.22 (12.69)	49.50 (14.91)
Shifting Attention Instruction Throughput	81.00 (14.45)	75.22 (17.36)	68.22 (17.10)	70.72 (19.72)
Symbol Digit Coding Throughput	37.25 (4.66)	34.73 (8.43)	32.02 (11.18)	29.54 (5.96)

[†] The pattern of reported results remained the same when the 79-yr-old CFII/ATP pilot was excluded from analysis.

TABLE II

LANDING AND HOLDING PATTERN ENTRY DECISION ACCURACY BY AGE AND EXPERTISE GROUP.

	Younger IFR/CFI	Younger CFII/ATP	Older IFR/CFI	Older CFII/ATP
Landing				
Adjusted Hits	0.50 (0.54)	0.36 (0.45)	0.31 (0.49)	0.17 (0.54)
False Alarms	0.22 (0.43)	0.28 (0.46)	0.44 (0.51)	0.44 (0.51)
Mean Misses	0.28 (0.35)	0.36 (0.38)	0.25 (0.31)	0.33 (0.30)
Sensitivity index (d')	1.25	1.30	1.04	1.21
Response bias (c)	0.35	0.32	0.16	0.17
Holding Pattern Entry				
Execution Accuracy	1.69 (0.49)	1.50 (0.64)	1.47 (0.68)	1.61 (0.68)

Numbers in parentheses denote SD. Sensitivity index and response bias were calculated across trials 2 and 3 only. Larger response bias scores indicate a higher tendency to avoid landing. Execution accuracy ranges from 0 – 2 correct.

TABLE III

RELATIONSHIP OF AGE AND EXPERTISE ON FLIGHT CONTROL. SUMMARY OF GLM RESULTS [PARAMETER ESTIMATES (SE) AND OVERALL R^2]

Variable (z-score units)	Intercept	Age	Expertise	Age × Expertise	F	R^2
Approach						
Lateral Deviations	0.003(0.081)	0.005(0.006)	−0.419(0.162)*	−0.006(0.012)	2.38	0.10
Ailerons	0.032(0.100)	0.014(0.007)*	−0.319(0.200)	−0.014(0.014)	2.54	0.09
Elevators & Altitude Deviations	−0.003(0.078)	−0.002(0.006)	−0.099(0.155)	0.007(0.011)	0.34	0.02
Holding Pattern						
Overall Deviation	0.068(0.124)	0.010(0.009)	0.217(0.248)	−0.019(0.018)	1.09	0.05
Altitude Deviation	−0.007(0.100)	0.009(0.007)	−0.005(0.200)	−0.007(0.014)	0.59	0.03
Speed Deviation	0.031(0.101)	0.002(0.007)	−0.150(0.202)	−0.009(0.014)	0.31	0.01
Bank Deviation	0.051(0.096)	0.025(0.007)***	−0.303(0.192)	−0.035(0.014)*	6.96***	0.24

Positive numbers indicate worse performance, e.g., greater deviations from the ideal flight path.

*
$P < 0.05$;

***
$P < 0.001$.