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The Impact of Training on General Aviation Pilots' Ability to Make Strategic Weather-Related Decisions

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16. Abstract

Inadvertent flight into hazardous weather can have devastating results for general aviation pilots (NTSB, 2005; Goh and Wiegmann, 2001). In fact, weather is the leading cause of fatalities in general aviation. The purpose of this study was to determine if a graphical weather display combined with an instructional training paradigm could improve pilots' ability to maintain a safe flying distance from convective thunderstorm activity. Previous research suggested that giving pilots the ability to see accurately the weather they are flying in and around may tempt some pilots to try to fly through small breaks in the convective activity. Indeed, Beringer and Ball (2004) found that pilots using graphical weather could be classified into two types of users (tactical vs. strategic). Tactical users were those pilots who used the information to try and navigate through or very close to the hazardous weather. Strategic users were those pilots who used the graphical information to plan and maintain a safe distance (20 nautical miles or greater) from the storm. An instructional slide presentation based on the Aeronautical Information Manual (AIM, 7-1-27) guidelines was developed with the intent of modifying the behavior of users classified as "tactical." Fifty-seven general aviation pilots were evaluated on a low-visibility visual flight rules (VFR) scenario where they encountered an encroaching thunderstorm traversing their flight plan. The pilots were separated into two groups, tactical or strategic users, according to how they responded to a simulated scenario of a VFR flight using a graphical weather display. Half of the pilots in each group then received training to see if it would decrease the incidence of tactical usage. Additionally, a control group was evaluated that flew the multifunction display without the graphical weather information. The hypothesis that training would improve the tactical pilots' ability to maintain a safe flying distance was supported. The analyses indicate that training lowered the tactical users from 100% tactical usage down to 44% tactical usage. It also significantly increased the average distance tactical users flew from the thunderstorm from 10.2 miles (SD = 4.0) to 31.3 miles (SD = 18.2); $t(8.76) = -3.401$, $p < .008$ (equal variances not assumed). The strategic and tactical untrained user groups were not significantly different from their respective control group (no training and no graphical weather) on how close they flew to the weather or cells.

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Contents

The Impact of Training on General Aviation Pilots' Ability to Make Strategic Weather-Related Decisions

One of the most dangerous flying situations a pilot can face is inadvertently flying into hazardous weather conditions. As a result of these incidents, the NTSB has countless reports of pilots being fatally injured. The following three cases illustrate the magnitude and vast variability of the pilots who have errantly succumbed to this fatal mistake.

On a night cross-country flight, an instrument rated pilot and friends were traveling in a Beech A36 equipped with a storm scope. At 8:27 P.M., the pilot contacted air traffic control for flight following, and shortly thereafter the controller observed the plane enter an area of adverse weather. At 8:36 P.M., radar contact was lost. A witness reported seeing the airplane come out of the clouds in a spin and hit the ground, bursting into flames (NTSB: CHI05FA020).

A private pilot was returning home in his just purchased Mooney M-10. At the time of departure, there were 1600 ft ceilings and 5 mi visibility, and the weather along the route was reported as instrument and marginal Visual Flight Rules (VFR). A witness reported that the pilot planned a route to fly south around the adverse weather and terrain. However, the planned route suggested by the witness would not have taken the pilot far enough south to avoid the hazardous weather. The plane wreckage was found in a steep hilly area along a direct course from the planned destination airport (NTSB: ANC06LA030).

A certified airline transport pilot, with nearly 17,000 hours of flight experience, was flying a Cessna 150 on a VFR cross-country flight. About 1.5 h into the flight, radar contact was lost. Prior to departure, the pilot had received a Flight Service Station weather brief. During the course of the brief, the briefer advised several times that a VFR flight was not recommended. According to a witness the weather was unusually foggy in the area. The pilot was fatally injured when the Cessna hit up-sloping terrain (NTSB: NYC06LA010).

A major safety concern for general aviation pilots is the danger associated with inadvertent flight into Instrument Meteorological Conditions (IMC). The National Transportation Safety Board (NTSB, 2005) reported that 6% of all general aviation (GA) accidents were the result of weather-related incidents. Of these accidents, 70% were fatal, which accounted for more than 25% of all GA deaths. This trend has been fairly consistent for some time and seems to persist across countries. Goh and Wiegmann (2001) found that between 1990 and 1997, 80% of accidents associated with inadvertent VFR flights into Instrument Meteorological Conditions (IMC) were fatal. In 1989, the NTSB reported similar fatality rates (72%) for weather-related accidents. Batt and O'Hare (2005) reported that 75.6% of VFR into IMC accidents, as reported by the Australian Transport Safety Bureau, were fatal. Reducing such accidents could greatly decrease GA fatalities.

Several theories have been suggested by researchers as possible explanations for why non-instrument rated pilots, who are legally required to avoid IMC, press on into such situations. One theory points to motivational factors that may contribute to a pilot's willingness to continue the flight into adverse weather (McCoy & Mikunas, 2000). This has commonly been referred to as "get-home-itis." Others have added that motivational factors are intrinsically based on gains and losses. O'Hare and Smitheram (1995) suggested that pilots who were focused on the gains associated with diverting were less likely to continue the flight than pilots who were focused on the loss associated with diverting.

Second, lack of experience and poor pilot assessment of the current situation have also been suggested as possible explanations (Klein, 1993; Goh & Wiegmann, 2001). The NTSB (1989) cited "overconfidence" as the result of 19% of the fatalities resulting from VFR into IMC crashes during 1983-1986. Wiegmann, Goh, and O'Hare (2002) found poor "situational assessment" and experience were negatively associated with continuing further and longer into deteriorating conditions. Additionally, they found that pilots who were less accurate at interpreting the visibility were more likely to continue the flight into IMC.

Alternatively, Knecht (in press) suggested that a select number of pilots tend to spend only a small amount of time obtaining preflight and enroute weather information. He found that 10% of pilots reported spending on average 9 min on preflight weather preparation and less than 2.5 min on enroute weather updates. Also, 5% of the pilots reported spending less than 7.1 min on preflight weather planning, and 1.8 min on enroute updates. Additionally, there were individuals spending as few as 3 to 4 min on preflight and less than 1 min on enroute updates. These results seem to indicate that there may be a select number of pilots that get into hazardous weather situations as a result of failing to obtain adequate information prior to their departure and also neglecting to continue to monitor the ever-changing environmental conditions.

Previous findings suggest a need to increase the sensitivity of pilots' interpretation of the surrounding weather and to promote an increased awareness about flying in and around hazardous storms. Wiggins and O'Hare (1995) have shown that pilots with lower levels of experience tend to have longer response latencies in determining a plan of action than pilots with more experience. Differences in experience suggest additional training or education is needed to elevate the inexperienced pilot's performance. More recently, Wiggins and O'Hare (2003) reported that a cue-based training system can improve a pilot's ability to recognize quickly when weather-related decisions need to be made.

Recent technological advances, such as onboard graphical weather depiction, have given pilots the ability to interpret with much greater clarity the weather conditions they are encountering. This new visual/graphical representation of the environment should improve pilots' ability to understand and interpret what they are encountering more quickly and efficiently. With this increased "situational assessment," pilots could make safer and more informed decisions regarding how to interpret and handle the weather they are facing.

However, due to the increased awareness of the environmental conditions, pilots are faced with a new potential danger. Higher display resolution may tempt pilots to take increased risks by flying between hazardous weather cells. High fidelity may tempt some pilots to misuse or misinterpret the graphical presentation of the environment. Beringer and Ball (2004) found that a select sample of pilots interpreted the higher-resolution images as an opportunity to fly through small breaks in the convective activity, disregarding the limitations of the technology. Reason (1997) has suggested that all safety technologies can be used in a manner that increases exposure to risk. For example, mining deaths *increased* after the invention of safety lights by increasing exposure to hazardous conditions. Thus, it is important to provide educational assistance for pilots that might intentionally or unintentionally misuse this potentially useful and rich information. Beringer and Ball (2004) found that pilots could be classified into two behavioral categories based on how they used the graphical weather display to navigate an encroaching thunderstorm. Those that exhibited behavior to avoid and/or navigate at a safe distance (AIM recommends 20nm) around hazardous weather were classified as "strategic" users. Pilots that navigated close to convective cells and/or attempted to navigate through small holes in the storm to reach their destination were categorized as "tactical" users. As these new technologies filter into the GA arena, it is important that we train and educate pilots about the potential dangers and pitfalls associated with the unintended use of systems or functions.

The purpose of this study was to determine if pilots who exhibit tactical behavior can be retrained to properly use the information to maintain a safe flying distance from convective activity. The first hypothesis was that an educational training paradigm can reduce the amount of tactical flying seen among pilots. Second, it was hypothesized that the graphical weather display would improve the overall ability of pilots to circumnavigate convective thunderstorm activity more safely and efficiently than pilots with no graphical weather information. Finally, it was hypothesized that the pilots with graphical weather information would decrease the number of radio calls they made asking for traditional weather information.

METHOD

Participants

Fifty-seven general aviation pilots were randomly recruited from the Oklahoma City, OK, area. Participants were required to have a minimum of a private pilot's license. Recruitment flyers were posted at several local flight schools and fixed based operators (two uncontrolled airfields, two Class-D airports and one Class-C airport). Additionally, several local flying organizations (Civil Air Patrol, Ninety-Nines, local Engineer Flying Club, a local Experimental Aircraft Association group) were e-mailed with the details of the study.

Apparatus

The study was conducted at the Civil Aerospace Medical Institute. Scenarios were flown in the Advanced General Aviation Research Simulator (AGARS). AGARS is a high-fidelity non-motion Silicon Graphics-based platform configured as a Piper Malibu. The cockpit contained conventional round-dial instrumentation with the exception of the multifunction display, which presented the NEXt generation weather RADar (NEXRAD) system and METeorological Aerodrome Report (METAR) information. Additionally, pilots could access text-based METARs for any of the surround airports that had traditional weather reporting stations.

Design

A 3x2 incomplete Randomized Block design was used. The independent variables were Group (6) and Training (2). The blocking variable was type of display usage (strategic vs. tactical). Group assignment was determined by having the pilots make a decision based upon viewing a series of NEXRAD images presented on a display similar to what they would be flying. Those pilots that made decisions consistent with the AIM (7-1-27) were categorized as Strategic users, and those that made decisions inconsistent with AIM 7-1-27 were categorized as Tactical users. Strategic usage included decisions to fly to an alternate airport, return to departure airport, fly around adverse weather to avoid encroachment of the storm by 20 nautical miles. Tactical usage was scored as behaviors that put the pilots closer than 20 nautical miles to the storm. This included pilots trying to fly between the critical convective cells or those pilots trying to cut through the edge of the thunderstorm. Half of the Tactical users and half of the Strategic users were then randomly assigned to the instructional paradigm on how to correctly use Flight Information Systems Data Link (FISDL) type of information. Dependent variables measured were Time to Initial Decision, Time to Final Decision, Proximity to the Storm, Number of Weather Inquiries, and Final Rating of how the pilot flew the scenario (Tactical or Strategic usage).

Additionally, a control group was tested to see how much of an impact the graphical weather depiction had on pilots' weather-flying decisions. The control group flew the same scenario with the same multifunction display, with the exception that they had no graphical weather presented on the display. They had to rely solely on the weather available from radio communications. Initially, this control group was seen as a single group, but during analysis the control group exhibited extreme variance in their behavioral responses. It was then decided that the group would be split into two groups based upon how they responded to the preflight screening tool used to categorize Tactical vs. Strategic flying behavior. The criteria used to categorize pilots in the control groups were identical to that used to classify pilots into the tactical and strategic groups.

Procedure

Upon arrival, participants filled out a consent form, a preflight experience questionnaire, and a risk assessment. Pilots were asked about any medical restrictions or waivers on their medical certificate. The only response to the question was that some pilots were required to wear corrective lenses while flying. All were given the option to terminate testing at any time without any consequences. Each pilot was then asked to view a series of six screen captures of the multifunction display. These static screen images had NEXRAD imagery overlaid on a moving map display. The static images were taken of the display that the pilots would be flying during the actual experiment, but the locations and weather representations were different. Pilots were instructed to imagine that they were flying a VFR flight. They were told that they would see a series of six slides that represented an incremental (six min) update on the weather information they were encountering. The display had a weather front moving into their destination airport. With every update, the ownship was getting closer to the destination airport and the thunderstorm. All pilots were instructed to maintain visual meteorological conditions at all times. At each slide, the pilots were asked if they would continue the flight based on the graphical depiction of the weather. The pilots were classified as Tactical users if they proceeded to the final slide and said they would try to land at the destination airport. If they said they would divert during any of the slides, they were classified as Strategic users.

Once the pilots were assigned to a group, they were then randomly chosen either to receive the training slide show, to not receive the training, or they were placed in the control group. At the end of the flight, the pilots were asked to fill out a questionnaire further describing the activities and decisions they made during the flight. All participants were monetarily compensated for their time.

Training

Training Paradigm for Flight Information Systems Data Link (FISDL). Training consisted of 38 slides that provided guidance on the proper usage of Flight Information Systems Data Link (FISDL) information. The researchers recommended using the information to augment traditional sources of weather information (radio and personal observation, VMC). FISDL information limitations were reiterated, and pilots were told to use the information to help create a route to navigate around and avoid critical weather. Pilots were specifically told not to use this information tactically, with specific examples to demonstrate the hazards of this type of behavior. The final few slides contained five multiple-choice questions based on the previous information. Answers were provided on the slide that followed each question.

Display Training. Pilots then watched a 20-min training video that was produced by the display manufacturer. The video contained information on the overall menu structure and layout of the system. Additionally, it demonstrated how to use all critical navigational controls and specified how to build and modify flight plans. It also presented information on how to interpret the graphical weather overlays (NEXRAD and METAR graphical data) and navigational symbology. Each weather overlay's function was discussed in detail.

Simulator Orientation. A review and orientation with the multifunction display and simulator was then given. Instruction included how to navigate through the display and how to access and interpret the FISDL data, specifically NEXRAD and graphical METARs. General guidance with the simulator controls and layout was also provided. In addition, a short session on how to use the autopilot was conducted. Pilots were then briefed about the flight scenario that included the route to be flown (shown on a standard VFR sectional and preprogrammed into the multifunction display), and they were provided with a Direct User Access Terminal System (DUATS) briefing for the flight. The flight scenario lasted, on average, 75 min.

Flight Scenario. The Scenario consisted of a direct VFR flight from Amarillo International Airport (AMA) to Will Rogers World Airport (OKC). Pilots were instructed to always maintain visual meteorological conditions, and they were asked to fly using the autopilot. The initial weather started out with 10 mi of visibility with a broken layer of clouds at 6000 ft. Along the flight path, the pilots encountered a thunderstorm tracking from southwest to northeast moving at 20 to 25 kt. As the pilots flew towards their destination (OKC), the environmental conditions began to deteriorate, with visibility and ceilings decreasing. Pilots were required to circumnavigate the thunderstorm and decide if they could continue to the destination. When the pilots reach 60 nm from OKC, the destination airport's weather dropped to below VFR minimums (2.5 nm visibility). The scenario was terminated when the pilot made a decision to land either at an alternate airport, at the original destination, or to return to the departure airport. Pilots' decisions were recorded when they made a heading change and voiced they were diverting. Those pilots who chose to proceed to the destination airport were advised when they made radio contact with the ATC Tower that the airport was IFR. The Tower then asked the pilot his or her intentions, and those requesting to land (special VFR) were scored as choosing to land at the destination airport as their final decision.

Analyses

The statistical tests used to determine differences between the groups were two-sample T-test and descriptive statistics. T-tests were employed because only specific comparisons were of interest. These comparisons were between the following groups: the tactical group vs. the tactical group with training, the tactical group vs. the tactical control group, the strategic group vs. the strategic group with training, the strategic group vs. the strategic control group, and the tactical vs. strategic group.

RESULTS

Demographics

Overall, the sample of 57 general aviation pilots had an average age of 42.4 (SD=16.1) years. Average total flight time for the entire sample was 1079.8 (SD=1548.3, Range = 40 to 13,500) hours. The average amount of VFR time reported was 902.5 (SD=1254.9) hours, and the average amount of IFR time was 174.5 (SD=509.8) hours. No significant differences were seen among the groups. See Table #1 for further age and flight hours listed by group assignment. Seven of the pilots were females. See Table #2 for a complete listing of males and females by group.

Table 1. Means and Standard Deviations by Demographic Variables for the Sample

	Demographic Variables (N=57)			
Group *(Sample Size)*	Age (years)	Total Flight Time (hours)	VFR Flight Time (hours)	IFR Flight Time (hours)
Tactical Untrained (n=9)	*38.4 (20.1)*	*744.1 (943.0)*	*708.56 (932.0)*	*22.6 (22.1)*
Tactical with Training (n=9)	*41.9 (19.8)*	*1050.0 (1527.4)*	*945.3 (1370.4)*	*98.0 (165.3)*
Strategic Untrained (n=13)	*47.9 (13.6)*	*1321.7 (1290.3)*	*946.9 (662.7)*	*393.9 (945.6)*
Strategic with Training (n=13)	*44.3 (15.1)*	*1040.8 (1933.8)*	*901.8 (1646.2)*	*119.7 (297.9)*
Control Strategic (n=6)	*42.0 (16.3)*	*1442.5 (2332.3)*	*1171.7 (2027.6)*	*163.5 (348.3)*
Control Tactical (n=7)	*34.7 (12.1)*	*862.2 (1499.2)*	*785.3 (1077.5)*	*171.9 (409.6)*

Table 2. Distribution of Males and Females by Group Count

Groups	Sex		Total
	Males	Females	
Strategic Untrained	9	4	13
Tactical Untrained	9	0	9
Strategic Training	11	2	13
Tactical Training	9	0	9
Control Strategic	5	1	6
Control Tactical	7	0	7
Total	50	7	57

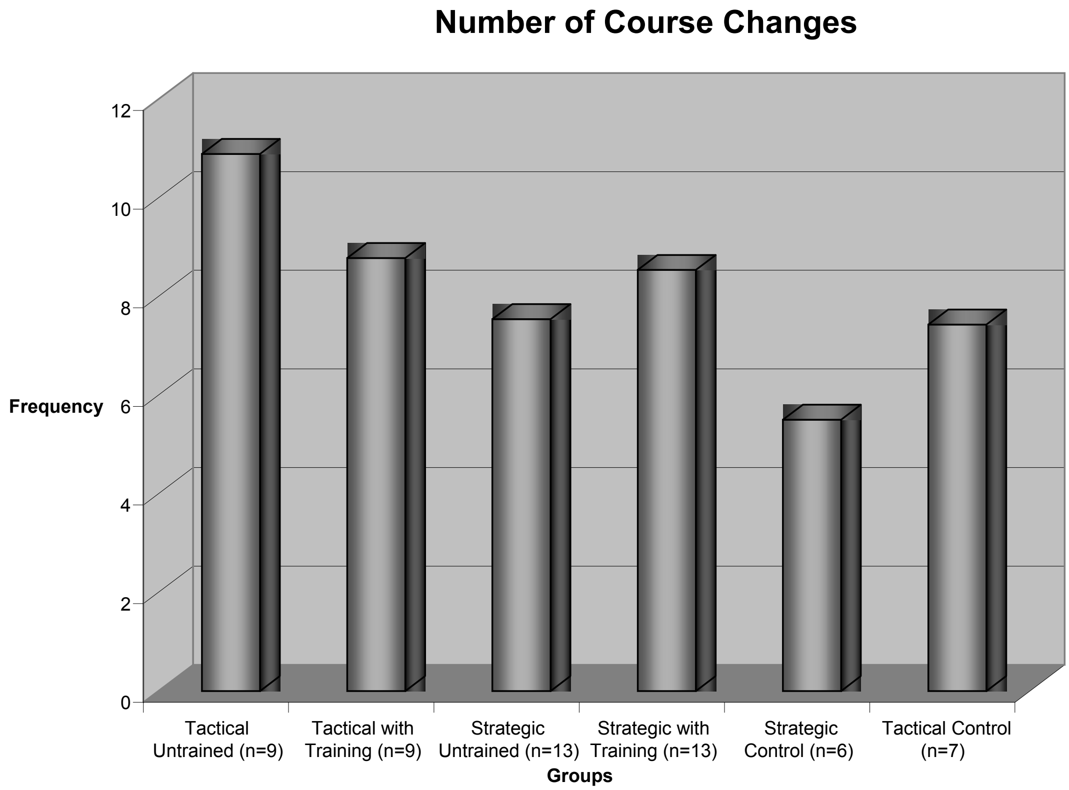

Figure 1. The average number of course changes made by the pilot during the flight.

Impact of Training on Tactical and Strategic Behavior

Course Changes. During the flight scenario, the total number of course changes was recorded for each pilot. Given that participants were using the autopilot, a course change was scored when the pilot made a heading change of more than 2 degrees from the current heading by adjusting the heading bug. The average number of course changes for the entire sample was 8.3 (SD=5.2). Tactical untrained users averaged 10.9 (SD=4.9) course changes; strategic untrained users averaged 7.8 (SD=5.3) course changes for the flight. Finally, the tactical and strategic control groups averaged 7.4 (SD=3.3) and 5.5 (SD=6.7), respectively. No significant differences were observed between groups with respect to course changes. See Figure 1 for a complete breakdown of course changes across each group.

Weather inquiries. Weather inquires were scored when the pilot accessed a weather overlay (graphical NEXRAD, graphical, or textual METAR reports) or requested weather from a radio source (ATIS, AWOS, FSS, control tower, etc). Tactical untrained users did not differ statistically from the Tactical users who received training on average graphical weather inquires (M=11.3, SD=9.2 vs. M=10.8, SD=6.5) or on radio calls for weather (M=3.3, SD=3.7 vs. M=4.11, SD=3.6). Strategic untrained users averaged 15.3 (SD=9.9) graphical weather inquiries and 1.5 (SD=1.6) radio calls for weather. Strategic users with training averaged 13.46 (SD=7.2) graphical weather inquires and 2.1

(SD=1.5) radio calls. The control groups did not have graphical weather, but they did have the ability to access weather through radio procedures. The average number of radio calls were 8.2 (SD=8.2) for the strategic control group and 8.0 (SD=6.9) for the tactical control group. See Figure 2 for a more complete breakdown of weather inquires across the groups.

Time to Make an Initial Decision. Pilots had to decide how and when to act to avoid the encroaching weather. The time from takeoff to the initial response to the weather is shown in Figure 3. An initial response was scored when a pilot decided to deviate from the original course. Tactical users with training (M=15.7 min, SD=5.0) made a decision sooner than the Tactical untrained user group (M=22.3 min, SD=6.9), t(16) =2.299, p=.035. The initial response made by the Strategic untrained group (M=16.3 min, SD=8.0) was significantly faster than the Strategic control group (M=28.2 min, SD=16.8), t(17)=-2.117, p=.049. No other comparisons (Tactical untrained vs. Strategic untrained, Tactical untrained vs. Tactical control, Strategic untrained vs. Strategic control) revealed any significant differences.

Average Time Pilots Took to Make a Final Decision. Pilots were required to make a second weather-related decision based upon deteriorating weather at the destination, and it involved the choices of landing at an alternate airport, returning to AMA, or landing at the destination (OKC). Time to a final decision was the elapsed time from take-off until the choice of an option regarding how to terminate the flight. The strategic control group was the quickest to reach a decision (M=44.5 min, SD=17.1). None of the comparisons between the groups reached statistical significance (tactical untrained vs. tactical training, tactical untrained vs. tactical control, strategic untrained vs. strategic training, strategic untrained vs. strategic control). See Figure 4 for the averages across groups.

How the Pilots Used the Display. Pilots were categorized by the experimenter according to how they used the display to circumnavigate the storm. If the pilots used the display to maintain a safe distance and separation from the storm, they were placed in the strategic flying category, and if the pilots used the display to attempt to navigate through the storm, thus breaching the AIM recommendation of maintaining 20 nm of separation, they were categorized as flying tactically. The control groups were also categorized as either flying the scenario tactically or strategically, depending on whether they maintained 20 nautical miles of separation from the thunderstorm. All of the pilots in the tactical untrained

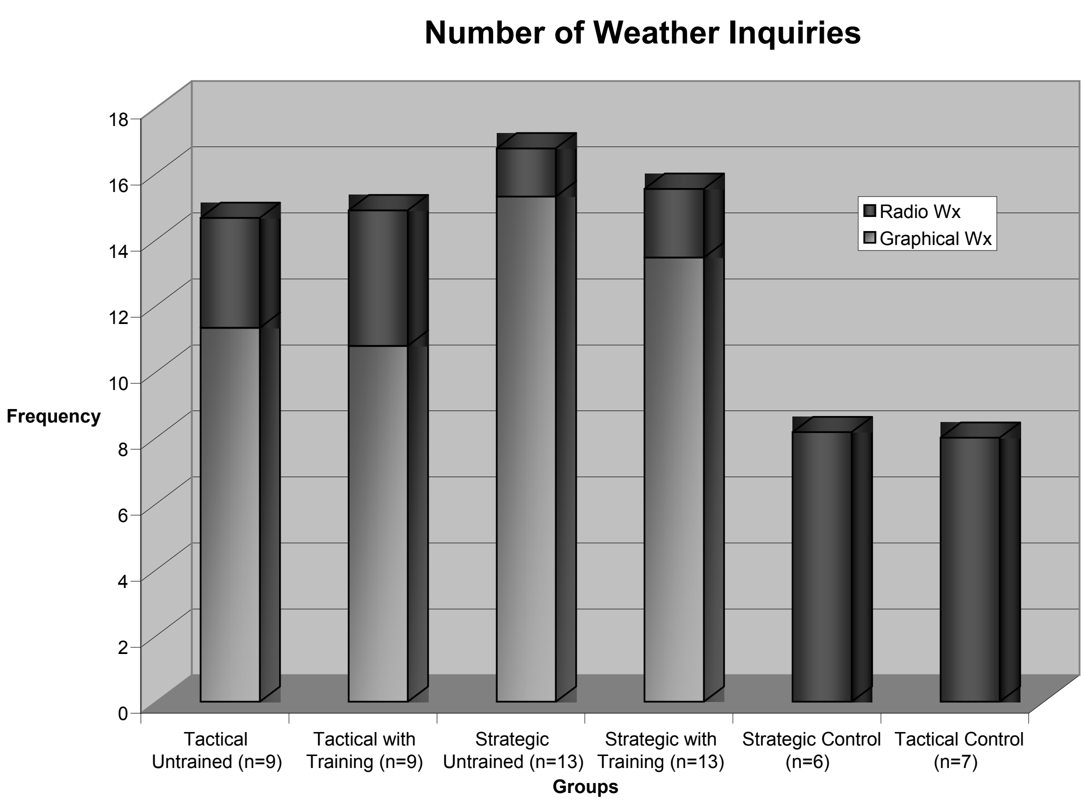

Figure 2. Number of graphical and radio weather inquiries. The control groups did not receive any graphical data.

Average Time to Make Initial Decision

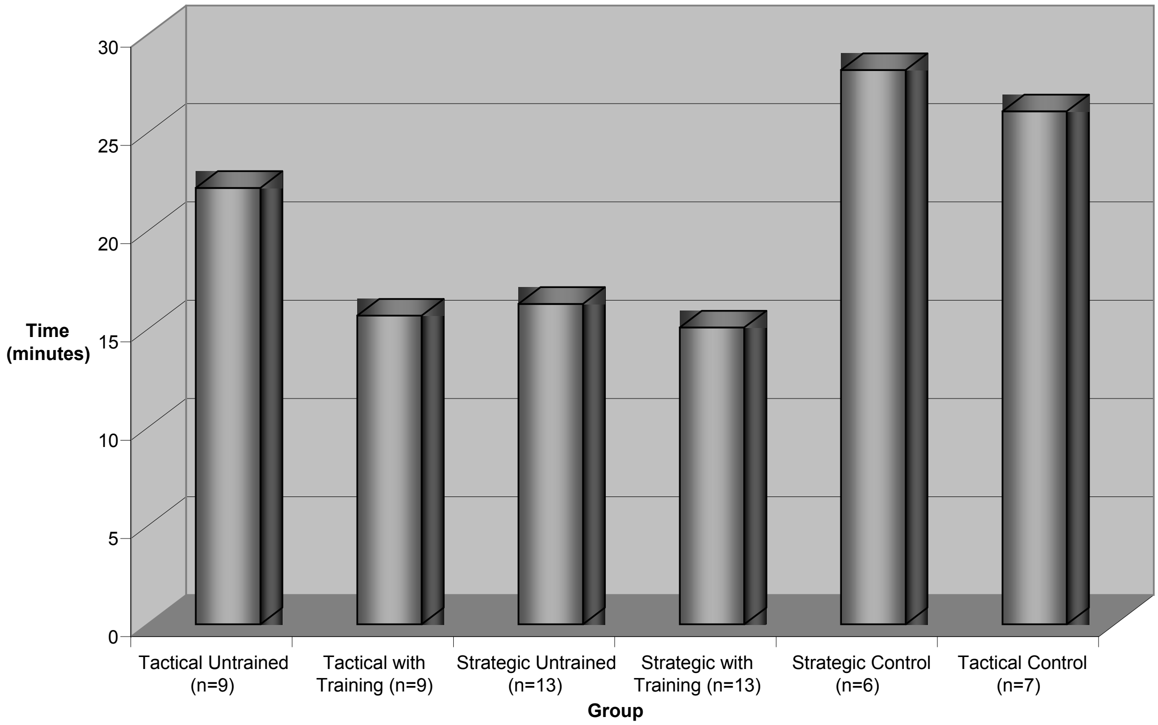

Figure 3. The average amount of time (minutes) the pilot took to make the initial decision to avoid the thunderstorm.

Average Time Pilots Took to Make Final Decision

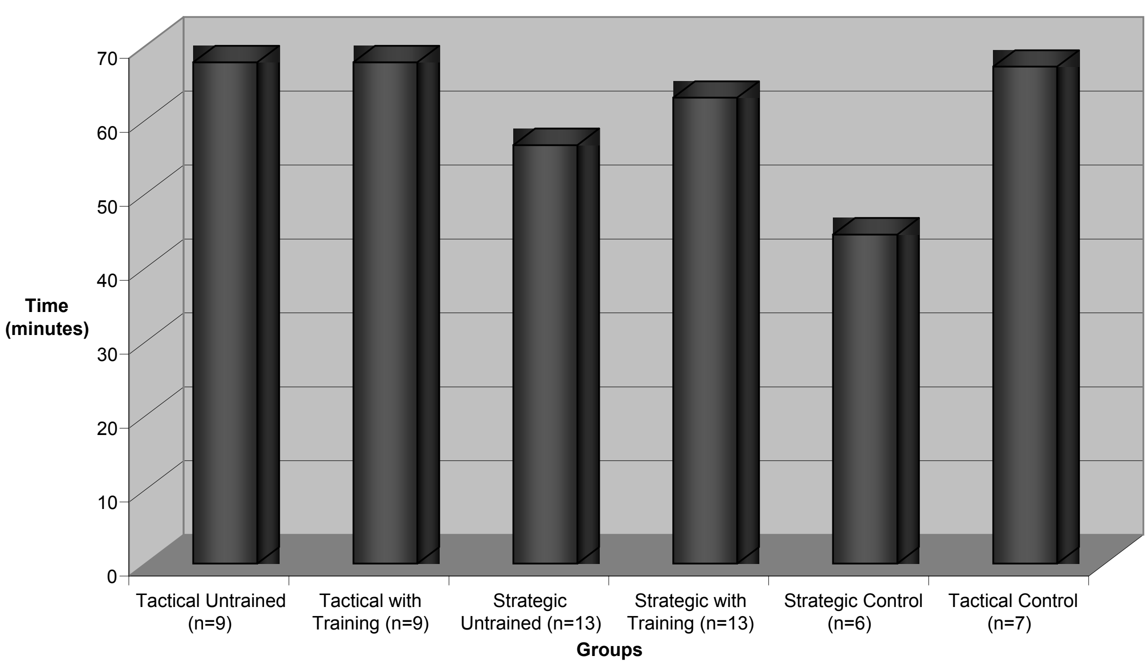

Figure 4. The average amount of time (minutes) taken by the pilot to make a final decision: land at alternate, land at destination, return to departure airport.

group flew the scenario tactically. Training lowered the tactical training group down to 44.4% tactical usage. Training had no affect on strategic users' type of flying. All of the pilots in the strategic control group flew the scenario strategically, and all of the pilots in the tactical control group flew tactically.

Final Decision Made by the Pilots. The final weather-related decision had to be made by the pilots to land at an alternate airport, return to AMA, or land at the destination (OKC). Even though the pilots had been instructed to maintain VMC, several pilots chose to continue on and land at OKC. Once the pilot contacted the tower to land at OKC, the pilot was scored as having decided to land at OKC. The pilot was then given a special VFR clearance to land at OKC and vectored to a runway. Once the other pilots chose to land at an alternate by initiating a heading change and (usually) a verbal indication that they were going to land at an alternate, the flight scenario was stopped and the pilots were scored as having decided to land at an alternate airport. Two pilots within the strategic control group chose to return to the departure airport (AMA). All of the pilots within the strategic untrained group diverted to an alternate airport. Three of the nine pilots within the tactical untrained user group landed at the destination airport and three out of the seven tactical control group pilots landed at the original destination. The group responses are summarized in Figure 6.

Table 3 further breaks down the pilots' final decision by their in-flight behavioral categorization (tactical or strategic). Eight of the tactical pilots landed at the destination airport, and 19 landed at an alternate airport. Of those pilots who exhibited strategic behavior, one landed at the original destination, 27 landed at an alternate airport, and 2 returned to the destination airport.

Closest Distance the Pilots Flew to the Thunderstorm. Training resulted in an increase in the distance that tactical users flew from the thunderstorm from 10.2 nm (SD = 4.0) to 31.3 nm (SD = 18.2), t (8.76) = -3.401, p< .008 (equal variances not assumed). The tactical control group also flew within 10.0 nm (SD = 7.9) of the thunderstorm. The strategic untrained group maintained 42.9 nm (SD = 33.3) of separation from the thunderstorm, while the strategic control group stayed on average 62.3 nm (SD = 44.9) from the storm. Training had no significant effect on the strategic training group, which flew within 31.3 nm (SD = 20.7) of the thunderstorm. Figure 7 represents these data.

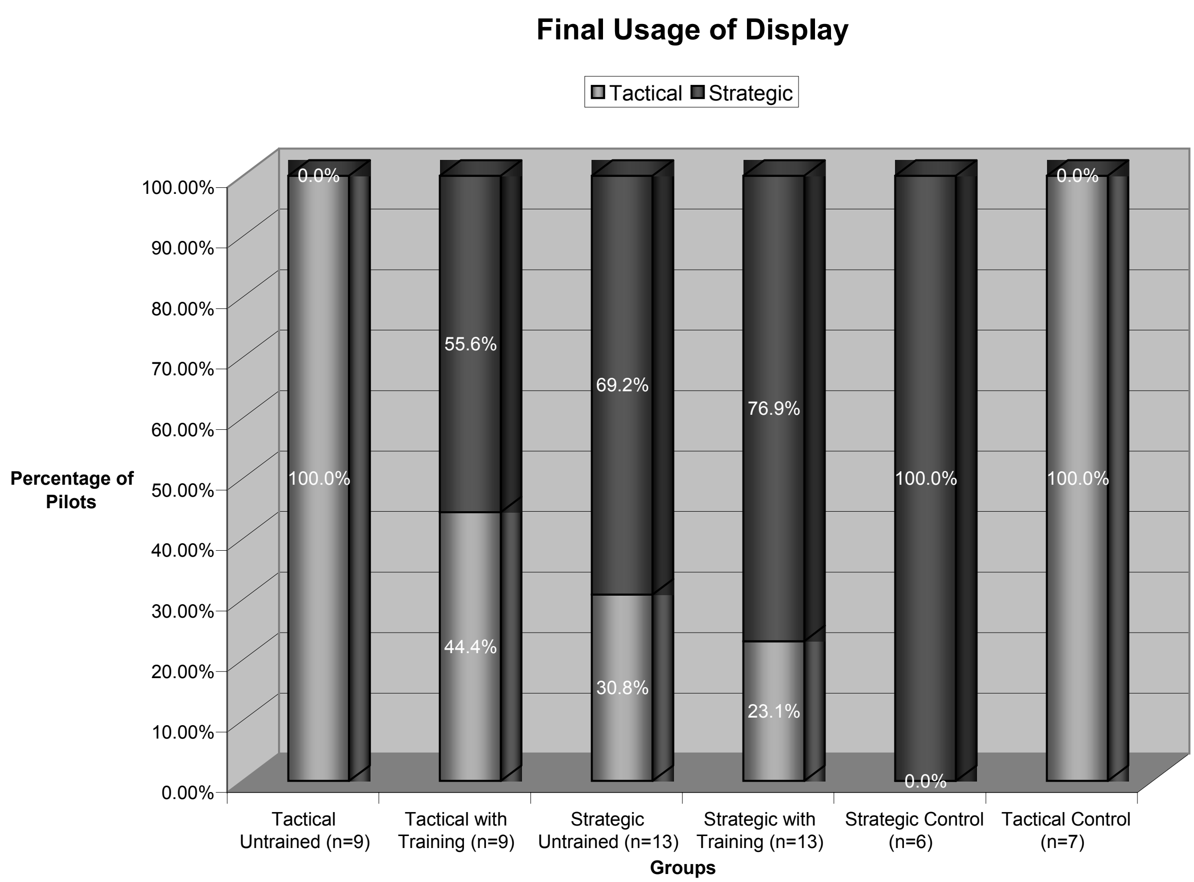

Figure 5. The categorical scoring of how the pilot flew the scenario with the display.

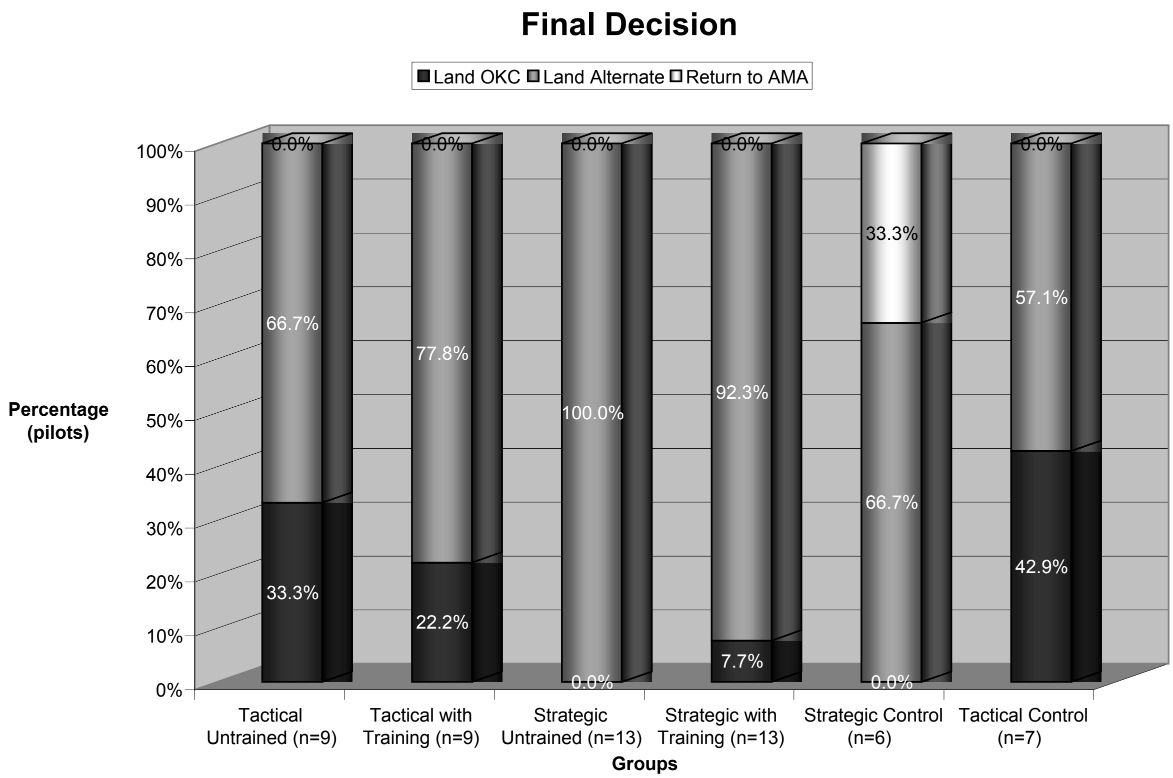

Figure 6. The Final decision the pilots made: return to departure airport (AMA), land at an alternate airport, or land at the destination airport (OKC).

Table 3. Distribution of Pilots' Final Decision, Broken Down by Type of In-Flight Behavioral Categorization (Tactical or Strategic) and Group Assignment

	Tactical Behavior		Strategic Behavior		
Groups	Landed at Destination	Landed at Alternate	Landed at Destination	Landed at Alternate	Returned to Departure Airport
Strategic Untrained	0	4	0	9	0
Tactical Untrained	3	6	0	0	0
Strategic Training	1	2	0	10	0
Tactical Training	1	3	1	4	0
Strategic Control	0	0	0	4	2
Tactical Control	3	4	0	0	0
Totals	8	19	1	27	2

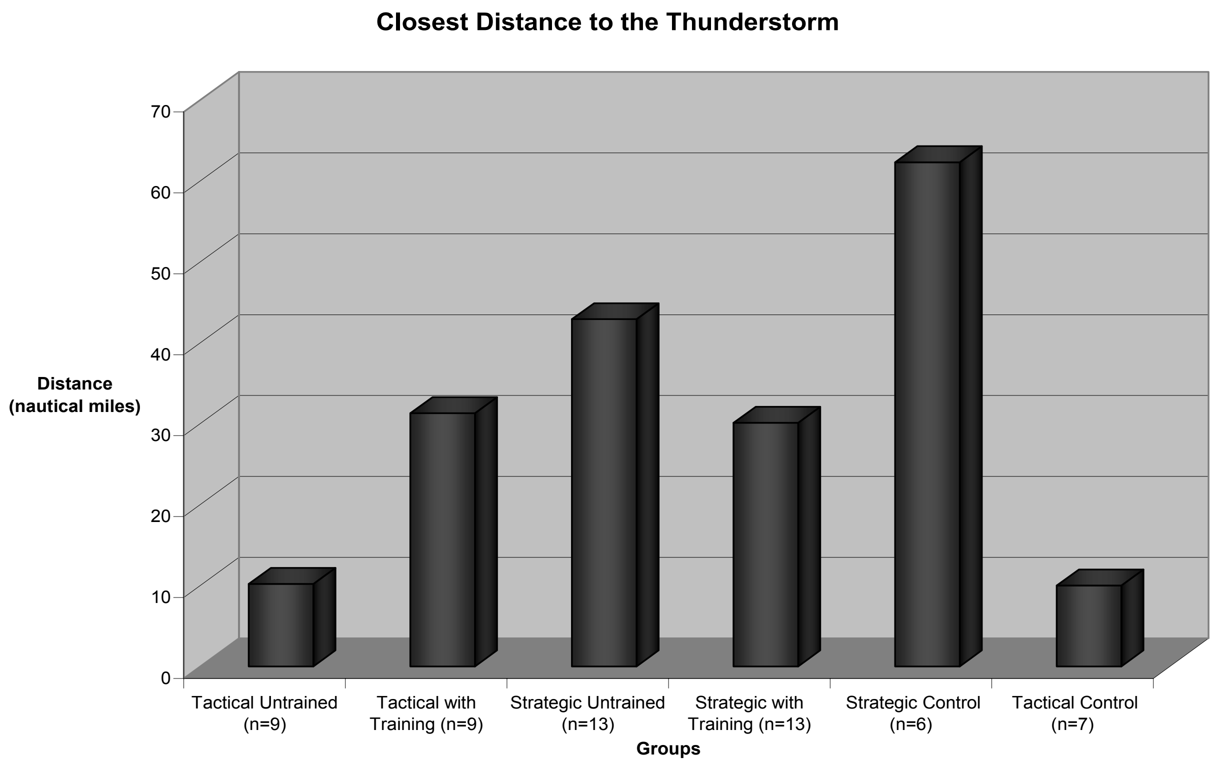

Figure 7. The closest distance the pilots flew to the thunderstorm.

Table 4. Closest Approach to the Destination Airport, Broken Down Into 10 Nautical Mile Increments

	Closest approach (nm) in nautical miles to the thunderstorm		
Group	d>20	20>d>10	d<10
Tactical Untrained	0	4	5
Tactical with Training	7	1	1
Strategic Untrained	9	3	1
Strategic with Training	9	2	2
Control Strategic	6	0	0
Control Tactical	1	2	4
Total	32	12	13
Total %	*56%*	*21%*	*23%*

AIM 7-1-30 recommends avoiding by at least 20 nautical miles any thunderstorm identified as severe or giving an intense radar echo. All indications given to the pilots were that the encroaching thunderstorm was severe. Table 4 breaks down across groups—how many pilots maintained the 20 nm separation and how many pilots flew inside 20 nm and 10 nm. Forty-four percent flew inside the 20 nm range. Twenty-three percent of the pilots flew inside 10 nm.

DISCUSSION

The results of this study provide evidence in support of training to reduce pilots' tendencies to fly tactically. Also, training improved tactical pilots' initial response times to deviate around the thunderstorm. Wiggins and O'Hare (1995) reported those pilots who were less experienced had longer response latencies in making weather-related decisions. Longer response latencies were hypothesized as putting the pilot into greater danger associated with flying further into deteriorating weather conditions before making a decision. Our second hypothesis predicted that having graphical weather onboard would improve pilots' abilities to safely and efficiently handle adverse weather conditions because of an increase in their time to respond to the situation as a result of improved situational awareness. The control pilots (no graphical weather) took longer to make an initial decision to circumnavigate the thunderstorm. Also, the strategic users elected to fly closer to the thunderstorm than did the strategic control group but still maintained the AIMS recommended distance (20nm separation) from the storm. This may suggest that the strategic group was able to navigate the storm more efficiently. Both training and graphical weather displays appear to increase the pilot's ability to make a decision sooner, which should prevent a pilot from inadvertently flying into IMC as a result of irresoluteness.

The third and final hypothesis predicted that pilots would neglect to use traditional sources of weather information (FSS, Flight Watch, ASOS, AWOS, etc.) because of the compelling presentation of the data. Pilots that flew the multifunction display with the graphical and textual weather overlays had a dramatically lower number of radio-related weather inquiries. Burgess (2002) presented similar findings that suggested pilots' overuse of the cockpit weather displays resulted in the reduction of accessing other sources of weather information. It appears that pilots tend to rely heavily on the graphical data and neglect the other sources of weather information. This is not surprising, given that the visual sensory system dominates human behavior. Pilots that neglect other sources of weather-related information limit their ability to develop a complete and accurate picture of the current weather situation.

One interesting finding was that several of the untrained strategic users and strategic users with training flew the scenario tactically. One possible explanation for this may be that these pilots were incorrectly categorized by our simulated VFR slide presentation; instead, perhaps they should have been classified as tactical users. It appears that these pilots cognitively knew how to respond in a strategic manner to such a weather phenomenon (response on the simulated slide presentation), but when they actually flew the scenario, they reverted to a more tactical approach. Furthermore, the idiosyncrasies associated with the simulated slide-show presentation and the actual simulator flight may have been different enough to elicit different behavior. The stress and workload associated with the flight were dramatically higher than the simulated slide show. The flight simulation lasted approximately 75 min, whereas the slide-show simulation took no more than 10 min to complete. The amount of time spent flying may have produced "motivation factors" to finish the scenario. This could be similar to the gains hypothesis where pilots saw diverting as a loss (O'Hare and Smitheram, 1995). Another possible explanation for the tactical behavior is that the pilots were experiencing a phenomenon similar to "get-home-itis." They could see it was going to take longer to fly around the edge of the storm than it would take to cut through the areas of broken activity, which would result in a significant savings of time. The "get-home-itis" theory seems vary plausible because, initially, all the pilots who had graphical weather and some of the control pilots made an initial decision to circumnavigate around the thunderstorm. It was not until later that many decided to cut through the edge of the storm. This is consistent with O'Hare and Owen's (2002) findings that weather-related crashes occur further into the flight and closer to the planned destination.

Furthermore, the "situational assessment" hypothesis (Goh & Wiegmann, 2002) could account for some of the tactical behavior that was observed. The pilots may not have fully understood the interpretation of the graphical depiction of the thunderstorm. Pilots may have thought it was allowable to fly in the areas of the graphical NEXRAD image that did not have severe cells (red cells) but were green (mild) and yellow (moderate). The trailing edge of the storm depicted broken cells with intensity in the mild (green) and moderate (yellow) range of intensities. Yellow cells indicated 30 DBZ to 45 DBZ of reflectivity, corresponding to approximately .175" to .5" of rain per hour. Yellow levels of precipitation often depict the intensity level at which radar echoes are generally considered convective, and therefore, common practice is to avoid these areas. The pilots in this study were told that the green areas were mild precipitation, the yellows areas were moderate, and the red areas were severe. One pilot actually commented during the post-flight interview that he generally would fly in yellow areas using his NEXRAD display and the intensity of the precipitation associated with the yellow areas was not that bad. The fallacy associated with this type of thinking fails to take into account the other hazardous weather events related to convective activity (lightning, severe winds, etc.). Pilots may need additional training on the significance of the color coding of the precipitation intensities and the dangers associated with flying in and around them.

Another plausible explanation for the results of this study could be a lack of pilot experience flying in hazardous weather. Although no statistical differences were seen in overall flight hours, there were differences in total IFR hours between the tactical untrained group and the other groups. The lower amount of experience in IFR conditions could indeed account for some of the tactical behavior seen among the tactical untrained group. This is consistent with Wiggins and O'Hare's (1995) findings that inexperienced pilots took longer to determine how to handle a hazardous weather scenario, thus causing them to fly closer to the weather. Less experience may indeed lead to slower decision making by inexperienced pilots, but the tactical control group, which had similar IFR experience as the strategic groups, exhibited very similar tactical flying as the tactical untrained group. This suggests that other factors are also at work. So, it appears the lack of hazardous weather flying experience and/or tactical flying tendencies play a role in the pilot's ability to make timely and safe decisions about flying in and around hazardous weather.

Hunter (2002, 2006), in a series of articles, suggests pilots' perceptions of risk are negatively associated with their level of risk tolerance. Hunter (2002) reported significant but small correlations between high risk perception and lower risk tolerance for high risk weather scenarios. This would suggest that those pilots who perceive more risk associated with adverse weather are less likely to engage in higher risk activities when dealing with weather. Further, he suggests that pilots with higher perceptions of risk tended to be less likely to engage in hazardous events. Hunter's work could also account for some of the behavior seen in this study. Those pilots who flew the scenario strategically may have interpreted greater risk associated with the hazardous weather than those pilots who flew the scenario tactically. This interpretation would imply that the training increased the pilot's perception of risk rather than skills for appropriate use of the display, leading to pilot behavior less willing to approach the hazardous weather, rather than clearer understanding of the capabilities and limitations of the display. Although risk perception may play a role in pilot risk taking, one can not separate it from other variables like lack of experience, poor situation assessment, motivational influences, and possibly other influences not yet determined, given the data available in this study. The training had the intended effect on behavior, but we cannot determine the underlying changes in pilot motivation or skill from the data at hand.

One final observation was that some pilots misinterpreted or failed to determine the direction of movement of the graphical depiction of the storm. The NEXRAD image was presented as a static simulation and only moved when the display received an update (no looping). As a result, several updates were actually needed to determine the direction of motion. Some pilots actually turned towards the north to circumnavigate the storm. Most later realized that this decision was not the most efficient and safe way to get around the storm, so they corrected their initial decision by turning south to go around the southern end of the thunderstorm. However, five pilots actually continued to fly around the north end of the storm. Two of the pilots finally decided to land at an alternate airport after they realized that they were not going to be able to outrun the storm. The remaining three continued around the storm until they were significantly past their destination. Two of the three pilots actually decided to cut through the storm and fly back to the destination. The final pilot decided to land at an alternate airport that was encapsulated within the bounds of the thunderstorm. These five pilots seem to exemplify the gains and losses hypothesis described by O'Hare and Smitheram (1995). It appeared that they had so much time invested that they were unwilling to change their original course of action. In the real world, similar decisions could result in devastating consequences.

A reduction in tactical flying would have a significant affect upon the general aviation fatality rate. A quarter of all general aviation deaths are the result of inadvertent VFR flights into IMC (NTSB, 2005). Training showed a positive impact on a flight's proximity to weather hazards. However, training did not change all tactical users' behaviors, which suggests that additional research is necessary to understand how to modify the remaining pilots' actions. Further investigation into more formal training is definitely warranted. Future research should also examine the lasting effect of such training. An immediate change in behavior is important, but changes in tactical behavior need to persist over time to have any real impact on the general aviation pilots.

REFERENCES

Batt, R. & O'Hare, D. (2005). Pilot Behaviors in the Face of Adverse Weather: A New Look at an Old Problem. *Aviation, Space, and Environmental Medicine, 76,* 552–9.

Beringer, D.B. & Ball, J.D. (2004). The Effects of NexRad Graphical Data Resolution and Direct Weather Viewing on Pilots' Judgments of Weather Severity and Their Willingness to Continue a Flight. (DOT/FAA/AM-04/5). Washington, DC: Federal Aviation Administration.

Burgess, M. (2002). The Effect of NEXRAD Image Looping and National Convective Weather Forecast Product on Pilot Decision Making in the Use of a Cockpit Weather Information Display. 3rd Annual NASA Weather Accident Prevention Project Review. Retrieved August 10, 2006, from: http://wxap.grc.nasa.gov/review/2002/A_Wednesday/2-AWIN/2-09_AWIN_Burgess.pdf.

Federal Aviation Administration. (2006). Aeronautical Information Manual: Official Guide to Basic Flight Information and ATC Procedures. Pittsburgh, PA: U.S. Government Printing Office.

Goh, J. & Wiegmann, D. (2001). VFR Flight Into IMC: A Review of the Accident Data. In Proceedings of the 11th International Symposium on Aviation Psychology. Columbus: The Ohio State University.

Goh, J. & Wiegmann, D. (2002). Human Factors Analysis of Accidents Involving Visual Flight Rules Flight Into Adverse Weather. *Aviation, Space, and Environmental Medicine, 73*, 817-22.

Hunter, D.R. (2002). Risk Perception and Risk Tolerance in Aircraft Pilots. (DOT/FAA/AM-02/17). Washington, DC: Federal Aviation Administration.

Hunter, D.R. (2006). Risk Perception Among General Aviation Pilots. *International Journal of Aviation Psychology*. 16, 135-144.

Klein, G.A. (1993). A Recognition-Primed Decision (RPD) Model of Raid Decision Making. In G.A. Klein, J. Orasanu, R. Calderwood, & C.E. Tzambok (Eds.), Decision Making in Action: Models and Methods (pp. 138-47). Norwood, NJ: Ablex Publishing Corp.

Knecht, W. (in press). Use of Weather Information by General Aviation Pilots, Part I, Quantitative: Reported Use and Value of Providers and Products. Federal Aviation Administration, Office of Aerospace Medicine, Washington, DC.

McCoy, E.C., & Mikunas, A. (2000). The Role of Context and Progressive Commitment In Plan Continuation Errors. *Proceedings of the 14th IEA Triennial Congress of the International Ergonomics Association/44th Annual Meeting of the Human Factors and Ergonomics Society* (pp. 26-29). Santa Monica, CA: Human Factors and Ergonomics Society.

National Transportation Safety Board (1989). Safety Report: General Aviation Accidents Involving Visual Flight Rules Flight Into Instrument Meteorological Conditions. (NTSB/SR-89/01). Washington, DC.

National Transportation Safety Board. (2005). Risk Factors Associated With Weather-Related General Aviation Accidents. (NTSB/SS-05/01). Washington, DC.

National Transportation Safety Board (2005). CHI-05FA020.

National Transportation Safety Board (2006). ANC06LA030.

National Transportation Safety Board (2006). NYC06LA010.

O'Hare, D. & Smitheram, T. (1995). "Pressing On" Into Deteriorating Conditions: An Application of Behavioral Decision Theory to Pilot Decision Making. *The International Journal of Aviation Psychology, 5,* 351–70.

O'Hare, D. & Owen, D. (2002). Cross-Country VFR Crashes: Pilot and Contextual Factors. *Aviation, Space, and Environmental Medicine, 73,* 363–6.

Reason, J. (1997). Managing the Risks of Organizational Accidents. Burlington, VT: Ashgate.

Wiegmann, D.A., Goh, J., & O'Hare, D. (2002). The Role of Situation Assessment and Flight Experience in Pilots' Decisions to Continue Visual Flight Rules (VFR) Flight Into Adverse Weather. *Human Factors, 44*, 189–97.

Wiggins, M., & O'Hare, D. (1995). Expertise in Aeronautical Weather-Related Decision Making: A Cross Sectional Analysis of General Aviation Pilots. *Journal of Experimental Psychology: Applied, 1,* 304–19.

Wiggins, M., & O'Hare, D. (2003). Weatherwise: Evaluation of a Cue-Based Training Approach for the Recognition of Deteriorating Weather Conditions During Flight. *Human Factors, 45,* 337–45.