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Situation Judgment and Action Selection: Roles of Expertise and Task Complexity

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This research examined the effects of pilot expertise on situation judgment and subsequent selection of actions as a function of situation complexity, flight element type, and control complexity respectively. Forty-seven certificated pilot participants were assigned to either a novice or an expert group based on their flight hours and experience. Each participant viewed flight goals and 54 flight scenarios that varied in complexity. Participants decided whether the flight scenario was consistent or inconsistent with the flight goal. Participants disclosed their selection of corrective flight control actions for the flight scenarios that they judged were inconsistent with the flight goal. The results suggested that novice performance consistently degraded as the flight situation complexity increased, whereas much less performance degradation was found for experts as the situation complexity increased. These findings were interpreted in the context of cognitive theories and potential applications of this research to analysis of pilot performance errors were discussed.

key words : expertise, pilot, situation judgment, action selection, task complexity

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Introduction

The term situation awareness (SA) originated in the aviation lingo by pilots, air-traffic controllers (ATC), and other aviation professionals to explain reasons for aviation accidents and by flight instructors for training purposes (Durso & Gronlund, 1999; Sarter & Woods, 1991). However, SA is often used broadly and there is no consensus of a precise meaning (Durso, Truitt, Hackworth, Crutchfield, & Manning, 1998; Endsley, 1995; 2000; Sohn & Doane, 2000). For example, some may attribute the tragic mid-air collision over Los Angeles in 1986 to low-level SA of the air-traffic controller. The highly publicized accident in 1999 of JFK, Jr. and occupants may have been a result of low-level SA, leading to disorientation of the altitude of the airplane. Although it was determined that the American Airlines crash outside of Cali, Colombia in 1995 was a result of incorrectly entering the code to the next waypoint, some can argue that had the pilots had greater SA of their position they would have deflected the course controlled by the flight management system when it turned towards an unsafe heading.

The greater interest in SA, as well as its proliferation into industries outside of transportation such as medicine, nuclear power plants, and intelligence has created a demand for a more precise definition and consequently sound instruments of measurement (Federico, 1995; Hoggs, Folleso, Strand-Volden, & Torralba, 1995; Xiao, Milgram, & Doyle, 1997). Endsley (1995) suggests that SA is processed at three levels: perception, integration, and projection of future status. Perception is the ability to perceive the relevant information. Integration allows the operator to comprehend various pieces of information into an understanding of the items being controlled by the operator as they relate to the environment. Projection is the ability to predict the changes to the status of the environment in the near future based on the operator's perception and integration.

Greater cognitive load and rate of accidents and error are inversely related to SA (Endsley, 1995; Orasanu, Martin, & Davison, 1998; Doane, Sohn, & Jodlowski, 2004). Increased workload and/or cognitive load may adversely affect one or more of the SA levels as posited by Endsley. Cognitive load increases as greater stimulus information presented increases, as greater operator demands increases, and as interactions and demands increase in complexity.

Complexity is the degrees to which the number of components, the degree of interaction between these components, and the dynamics and rate of change the components are increasing (Endsley, 1995). The greater the interaction of sequence-dependent flight control changes a pilot plans, the more complex the situation becomes (see, e.g., Doane, Sohn, &

Jodlowski, 2004; Sohn & Doane, 1997). That is, a change of one of the flight conditions is frequently interdependent with one or more other flight conditions. For example, a climb in altitude frequently precipitates a loss of airspeed. Similarly, any corrective control task is frequently interdependent with other control inputs.

This research explores the differences between novice and expert pilots. Greater than 1/3 of all general aviation accidents in 2001 involved pilots with less than 500 hours of total flight time (AOPA, 2003). However, only a small percentage of this group involved student pilots. That is, many of the pilots involved in these accidents had previously demonstrated the necessary skills to obtain a license. Piloting an aircraft constitutes a fast changing dynamic environment. For safe flight, interpretation, expectations, and plans of action frequently have to be processed in a fraction of a second.

Ericsson and Kintsch (1995) purport that experts are more efficient at integrating items from knowledge structures in long-term memory that interact with working memory. This mechanism is called long-term working memory (LT-WM). Experts have developed more sophisticated knowledge structures that allow them to quickly incorporate applicable knowledge that is used in the current situation. Having this ability allows the expert to process greater information than a novice who has not developed sophisticated knowledge structures (Larkin, McDermott, Simon, & Simon, 1980; Simon & Chase, 1973; Sohn & Doane, 2003).

By utilizing LT-WM, experts maintain SA better than novices, particularly when the situation becomes more demanding and complex. That is, experts have greater cognitive resources available than novices by retrieving information from their knowledge structures. As a result, as complexity increases experts are more accurate than novices at identifying if the airplane is on course with its intended flight goal elements (e.g., heading, altitude, airspeed). As the control actions become more complex, experts are also more accurate than novices in identifying the necessary changes to flight controls required to correct for deviations from a flight goal.

Present Research

The present research investigated the effects of expertise on situation judgment and selection of actions as a function of complexity. This experimental study was a mixed design with two expertise levels: novices and experts. Participants were presented with a flight goal to memorize, followed by a flight scenario representing flight situations that varied in the level of complexity. Each flight situation was either consistent with a flight goal or had one, two, or three flight elements (airspeed, heading, and altitude) that were inconsistent with the flight goal. For each inconsistent flight goal, one, two, or three flight control actions were required to make the flight situation consistent with the flight goal.

Many of the inconsistent flight situations had a matching number of corrective control tasks to the number of inconsistent flight elements. For example, some flight situations required two control movements to control for two inconsistent flight elements. Other flight situations had an unequal match of control movements required for the number of inconsistent flight elements. For example, some inconsistent flight situations required only one control movement for a flight situation that had two inconsistent flight elements; or three control movements for a flight situation that had two inconsistent flight elements.

Method

Participants

Fifty pilots participated in the two-hour experiment. The addresses of Federal Aviation Administration (FAA) certified fixed-wing aircraft pilots in Connecticut, U.S.A. were obtained from the FAA office in Oklahoma City, OK. Recruitment letters were sent to the pilots requesting their participation in this study. Fifty respondents were self-selected to participate and were paid $40 each for their participation. One of the pilots failed to complete the experiment and two of the pilots did not completely understand the instructions and procedures requested of them. The data collected from these three participants were deleted from the analyses.

The pilots were assigned to either a novice group or an expert group. Pilots with an instrument rating were assigned to the expert group and pilots without an instrument rating were assigned to the novice group. However, any instrument rated pilot who had less than 700 hours total flight time; less than an average of 125 flight hours per year; and less than 25 hours of flight time within the last 90 days was assigned to the novice group. Pilots who were not instrument rated but had over 700 hour of total flight time; more than an average of 125 flight hours per year; and more than 25 hours of flight time within the last 90 days were assigned to the expert group. The novice group comprised 29 participants with a mean age of 44.72 years, 336.2 mean total flight hours, and an average of 11 flight hours within the last 90 days. The expert group consisted of 18 participants with a mean age of 39.61 years, 2,578.8 mean total flight hours, and an average of 94.2 flight hours within the last 90 days.

Materials

Adobe Photoshop, Aftereffects, and Real-time player software packages were used to create the animation of the seven basic aircraft instruments:

airspeed indicator, altitude indicator, altimeter, turn coordinator, heading indicator, vertical speed indicator (VSI), and the RPM gauge. Flight scenarios were created using representation of the seven instruments configured similarly to a general aviation aircraft instrument panel and presented to the participants as dynamic flight situations.

Each flight scenario lasted 35 seconds with the first five seconds of the presentation static and the remaining 30 seconds representing a dynamic flight situation. Having the first five seconds of the scenario static allowed the participants to become acclimated to the flight situation before it became dynamic.

Fifty-four flight scenarios were created. Each flight scenario was preceded by one of six flight goals. A flight goal comprised a cardinal heading, an altitude (500 ft to 5500 ft) rounded to 500 ft, and airspeed rounded to 5 knots. A flight scenario was either consistent or inconsistent with its respective flight goal. A total of 30 inconsistent and 24 consistent flight scenarios were created for the experimental trials of which a total of nine (five inconsistent and four consistent) flight scenarios corresponded to each flight goal.

A consistent flight situation was defined as occurring when the flight scenario indicated that all flight elements had stabilized at the flight goal or would reach the flight goal in the near future without any manipulation of the controls. An inconsistent flight situation was when an immediate manipulation of the controls was required to bring any one or more of the flight elements consistent with the flight goal. For example, suppose an flight goal of heading 90, altitude 3500 ft., and airspeed 110 knots was presented to the participant. If the flight instruments indicated that the airplane had descended and stabilized at 3600 ft., undershooting the altitude goal of 3500 ft. by 100 ft., declined in airspeed and stabilized at 120 knots, 10 knots higher than the airspeed goal of 110 knots, and overshot the heading goal of 90 and stabilized at 110, then this scenario should be inconsistent with the flight goal. Both flight situation and corrective control actions required were manipulated by complexity.

Complexity of a flight situation was manipulated by the number of inconsistent flight goal elements in the flight scenario, such that an inconsistent flight scenario had one, two, or three inconsistent flight goal elements. Among the flight goal elements, three key elements (airspeed, altitude, and heading) were selected. For example, if the airspeed was inconsistent with the flight goal, but the altitude and heading were consistent, then only one of the elements of the flight goal was inconsistent.

Complexity of control movements (planning actions) was manipulated by the number of aircraft control changes needed to correct for an inconsistent flight scenario. For each flight scenario inconsistency, one, two, or three aircraft control movements were required to correct for the inconsistency and to bring the flight situation consistent with the flight goal.

Procedure

Each trial began with a text description of the flight goal. The participant was instructed to memorize the flight goal and press the space bar to bring up the animated 35-second flight scenario. Once the participant pressed the space bar, the flight goal was removed and the participant was unable to bring that page back. Participants were not allowed to write down any information during the trials.

Immediately after the flight scenario ended, a screen appeared prompting the participant to press a key marked Consistent (C) indicating that the flight situation was consistent with the respective flight goal or a key marked Inconsistent (I) indicating that the flight situation was inconsistent with the respective flight goal. If a participant chose the inconsistent key, he or she was asked by the experimenter to indicate which controls should be manipulated to make the flight situation consistent and to specify the flight goal elements that were inconsistent. This prompt by the experimenter was intended to stimulate think aloud procedures to capture what the participant's plan of action was. Hayes-Roth and Hayes-Roth (1979) and Xiao, Milgram, and Doyle (1997) have used this type of procedure for measuring action plans. Participants responded to a total of 54 scenarios for about two hours. To complete each task, they could have enough time and there was no time limit.

Analyses and Results

The data analyses are presented in three sections. The first section includes all data analyses of novice and expert differences as a function of the flight situation. The second section consists of analyses that were conducted on novice and expert differences as a function of flight goal elements (i.e., differences in identifying specific goals such as airspeed, heading, and altitude rather the complexity of the flight situation). The last section is devoted to novice and expert differences as a function of the corrective control actions required.

The data for the flight situation, flight goal, and corrective control analyses were scored by taking the percent correct that participants gave for each trial. For example if a participant correctly identified 18 of the 24 trials, then that participant received a score of 75% for identifying that level of flight situation.

Situation Complexity Analyses

An ANOVA on percent correct performance with expertise level as a between-subjects variable

Table 1. *Mean Accuracy for Novices and Experts across Situation Complexity.*

	Novices		Experts	
Complexity	*M*	*SD*	*M*	*SD*
Consistent	90.08	9.86	90.28	8.69
1 Inconsistency	72.41	10.91	77.22	10.18
2 Inconsistencies	71.7	10.76	78.24	6.94
3 Inconsistencies	62.21	10.02	73.38	11.27

and situation complexity as a within-subjects variable shows that there were main effects of expertise level, F(1, 45) = 8.21, p < .01, and situation complexity, F(1, 45) = 52.02, p < .01, and an interaction between expertise levels across complexity, F(3, 135) = 3.00, p < .03. Table 1 shows that expert and novice performance accuracy degraded as the situation became more complex, but performance degraded to a greater extent for novices than experts as the situation became more complex.

An inspection of Table 1 reveals that experts and novices did not differ in performance when the flight scenario had no inconsistent flight elements. In fact, on average, both novices and experts correctly identified approximately 22 of the 24 consistent flight scenarios. One can see from this table, however, that as the situation became more complex the difference of the performance between novices and experts became farther apart. A significant difference appeared between novices and experts at the most complex level of three inconsistent situations, but significant differences between the groups were not found at the other levels.

Flight Goal Analyses

An ANOVA with expertise level as a between-subjects variable and the type of flight element (e.g., airspeed, heading, altitude) that was inconsistent as a within-subjects variable was also conducted on percent correct performance. As a result, there were main effects of expertise level, F(1, 45) = 12.59, p=.01, and flight element, F(2, 90) = 14.85, p=.01, and an interaction between expertise level and flight element, F(2, 90) = 6.68, p=.01. As depicted in Table 2, novices identified flight goal element inconsistency when the inconsistent flight goal element was altitude more often than it was airspeed or heading. However, experts noticed flight goal element inconsistency when the inconsistent flight goal element was heading with as much accuracy as it was altitude. The performance gap between novices and experts

Table 2. *Mean Accuracy of Novices and Experts in Identifying Flight Goal Element Inconsistencies*

	Novices		Experts	
Flight Goal Element	*M*	*SD*	*M*	*SD*
Airspeed	65.15	10.28	66.96	9.69
Altitude	73.83	9.06	80.05	8.84
Heading	62.27	14.45	78.43	10.29

was the most prominent when the flight goal of heading was inconsistent.

Stated differently, both novices and experts recognized when altitude was inconsistent more frequently than heading or airspeed. The altitude is relatively easier to notice than the heading. Accordingly, when pilots should evaluate the present situation and predict the near future, experts notice both altitude and heading whereas novices notice just altitude because novices experience working memory overload. With terrain clearances, one would expect altitude to be one of the most important flight elements for a pilot. The data also revealed that heading was just as important of a flight element as altitude for experts, and heading was correctly identified significantly more frequently by experts than novices. These findings suggest that when cognitive load interfered with the novice identifying all inconsistent flight elements, he or she seemed to pay more attention to altitude. However, experts were able to identify heading inconsistencies as frequently as altitude inconsistencies because they may have had more working memory available to them that allowed them to notice additional inconsistent flight elements.

Control Complexity Analyses

An ANOVA on percent correct performance with expertise level as a between-subjects variable and control complexity as a within-subjects variable shows that there were main effects of expertise level, $F(1, 45) = 34.85$, $p < .01$, and control complexity, $F(2, 90) = 389.36$, $p < .01$, though no interaction between expertise level and control complexity was found, $F < 1$. As depicted in Table 3, overall performance was greater for experts than for novices and performance for both groups decreased as control complexity increased.

These results fail to support that novices' degradation in performance would increase to a greater extent than experts' as the control movements required became more complex. This might occur due to the fact that determining which control movement should be used to

Table 3. *Mean Accuracy for Novices and Experts across Control Complexity*

	Novices		Experts	
Complexity	*M*	*SD*	*M*	*SD*
1 Control movement	67.21	14.98	77.78	13.84
2 Control movements	51.17	8.01	60.06	8.93
3 Control movements	38.07	10.04	49.17	10.43

correct for an inconsistent flight situation can be somewhat subjective in certain circumstances. The control movement stimuli that were chosen as the correct answers were designed to be the best methods of correction, but not necessarily the only methods of correction. That is, one situation could require two control movements for the best method of correcting for an inconsistent flight situation, but one control movement would have sufficed. For example, applying power and reducing bank may be the best control action for gaining altitude, but although reducing bank helps to increase the loss of the horizontal component of lift, the increase in power alone will also correct for the correction for altitude.

Experts actually tended to use more idiosyncratic strategies to correct for the inconsistency and to bring the flight situation consistent with the flight goal than novices. The idiosyncratic strategies were not counted for corrective control actions because they are not the same as the predetermined criterion for correct answers. The experts' strategies, however, were adequate to correct inconsistency. As the number of control movements required increased, their tendency to use their strategies also increased. This might be a reason why the results didn't show that experts' degradation in performance would increase to a smaller extent than novices' as the control movements required became more complex.

It appeared that some of the participants might have had different understandings of what to accomplish by the control actions. Some participants had an understanding that their task was to only correct for the inconsistencies without regard to how the movement would affect the flight elements that were consistent. Other participants considered how the control movements they recommended to correct inconsistent flight elements would affect the consistent flight elements.

General Discussion

The main goal of the present research was to determine the effects of expertise on situation judgment and subsequent action selection as a function of situation complexity, flight element type, and control complexity respectively. Of the most interest was a precipitous degradation in performance initially (from consistent to one inconsistent flight element) for both novices and experts. However, for experts there were no significant performance differences between each level of complexity for inconsistent flight situations. Conversely, novices showed significant performance degradation as the situations became more complex.

This interaction between expertise and situation complexity corroborates research that suggests knowledge structures facilitate one's performance as a situation becomes more complex. (Doane, Sohn, & Jodlowski, 2004; Simon & Chase, 1973; Sohn & Doane, 1997). The more complex a situation becomes the greater the need for a pilot to compile the appropriate sequence-dependent relationships to adequately assess the situation. For example, an increase in power (RPMs) may affect altitude, airspeed, the rate of turn, or a combination of all three. Knowing which flight element increased RPMs will affect specific control action of each flight situation. This awareness guides the pilot in searching for specific stimuli to assess the current situations and make predictions of the future flight status.

Although having the skills to interpret the instruments effectively is an important factor, the ability to group several units of stimuli together allows for a better assessment of a flight situation. That is, a pilot must keep in working memory information such as "The power is increasing, but the airspeed is dropping, therefore, the airplane is in a climb, but if the rate of turn is increasing then it's possible that the airplane is not in a climb, but rather in a descent. However, the altitude is stabilized, so the airplane must have just leveled off from a descent. Skill is required to understand these sequence-dependent relationships, but it would be difficult for a pilot to effectively assess a flight situation if each relationship was kept as individual units of information. During some of the trials, many participants would say statements such as "How can the power be decreasing while the altitude and airspeed are both increasing?" Typically a decrease in power results in a decrease in airspeed, altitude, or both. The answer to the participant's question was that the airplane was leveling off from a climb. The airplane was reducing power and pitching forward. The pitching forward of the airplane was the reason for the increase in airspeed, and the plane was still in a climb, although at a slower rate. Once participants were offered this information, it was obvious to him or her that the airplane was leveling off from a climb.

We suspect that a novice notices an inconsistent flight element and begins planning a corrective control action. However, this process of determining which controls to manipulate to correct for the inconsistent flight situation requires greater cognitive load, and therefore the novice fails to process other elements of the flight situation. However, an expert may be reducing cognitive load by utilizing knowledge structures in LT-WM, consequently processing additional inconsistencies and corrective control actions.

The experts' developed knowledge structures may also explain why they were able to notice both inconsistent altitude and heading elements equally well. Novices may have been planning control actions to correct for the altitude inconsistency, thereby failing to notice other flight element inconsistencies with as much accuracy.

Despite the main effect found between novice and experts for corrective control actions required, expert performance degraded at a continuous rate as the control actions required became more complex. However, experts were more able than novices to correctly identify situations that required greater control actions to correct for an unequal number of inconsistent flight goal elements. That is, a change in power and pitch may be required to correct for only one inconsistent flight goal element such as altitude.

The findings of this research warrant further investigation. It seems that the interaction of accuracy in this simulated flight situation between novices and experts as the flight situation became more complex may be the result of experts having more cognitive load available that allowed them to make more accurate assessments of the situation. Additional research to test this theory is warranted.

A different type of control action task and more precise stimuli design and instruction should be used in any replications of this study. Additionally, an equal combination of all possible conditions between situation and control movements would allow the experiment to be analyzed as a three-way interaction. For example, if there were 10 situations that have two inconsistent flight elements matched with 2 corrective control movements, then there also needs to be 10 situations that have two inconsistent flight elements matched with 3 corrective control actions, or 10 situations that have one inconsistent flight element matched with 2 corrective control movements.

In this experiment participants were only passively viewing the presentation of an aircraft situation on a computer screen. Additionally, each trial depicted a dynamic flight situation that required the participant to acclimate to the situation without prior knowledge of the flight situation previous to beginning the task. Many participants felt that entering a flight situation mid-stream made the tasks more difficult. However, these findings have important relevance in today's world of automation and situation awareness. Since many aircraft flights utilize the convenience of autopilots, all too frequently pilots are required to jump into the flight situation mid-stream.

Many of the performance differences between novices and experts found in this study were due to the skill that the experts had acquired from frequent practice. However, have experts developed more sophisticated knowledge structures than novices that facilitate skill acquisition? The results of the situation analyses suggest that expert pilots may have developed knowledge structures to help reduce cognitive load and facilitate their capabilities of assessing a flight situation. If knowledge structures are used by expert pilots, then training aids for developing these types of structures should be included in a future pilot training curriculum. Salas, Cannon-Bowers, Fiore, and Stout (2001) have addressed the importance of training in situation awareness, but integrating the development of knowledge structures may produce a fecundity of positive results.

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상황 판단과 행위 선택: 전문성과 과제 복잡성의 역할

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이 연구는 조종사의 전문성 정도가 상황 판단과 그에 따른 행위의 선택에 미치는 효과가 상황의 복잡성, 비행 요소의 유형, 조작의 복잡성에 따라 각각 어떻게 다른지를 분석하였다. 47명의 조종사 참가자들이 비행 시간과 경험을 기준으로 초보자와 전문가 집단으로 구분되었다. 본 실험에서 참가자들은 비행 목표와 비행 시나리오를 보고, 제시된 비행 시나리오가 비행 목표와 일치하는지 또는 불일치하는지를 판단하였다. 각 참가자들에게 제시된 비행 시나리오는 복잡성 정도에서 차이가 나는 54개의 상황으로 구성되었다. 참가자들이 비행 목표와 불일치한다고 판단한 시나리오에 대해서는 비행 목표와 일치하도록 현 비행 상황을 수정하기위한 일련의 조작 행위를 선택하도록 하였다. 연구 결과를 볼 때, 초보자의 수행은 비행 상황의 복잡성이 증가함에 따라 지속적으로 저하된 반면, 전문가의 경우는 비행 상황의 복잡성이 증가함에 따른 수행 저하가 상대적으로 작게 나타났다. 이런 결과들이 인지 이론의 맥락에서 해석되었고, 끝으로 이 연구의 제한점, 시사점, 향후 연구문제가 논의되었다.

주요어 : 전문성, 조종사, 상황 판단, 행위 선택, 과제 복잡성