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조종실 계기 및 제어 복잡성이 조종사의 상황인식에 미치는 영향*

Effects of Cockpit Display and Control Complexity on Pilot Situation Awareness

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Abstract : This research extends a general theory of human cognition to an applied domain of piloting skills. We examined how fast and accurately pilots achieve and maintain situation awareness in flight by measuring their consistency judgment between a written statement describing a flight situation and a cockpit display showing a current state of an aircraft. The goal of this research is to determine whether situation awareness is influenced by expertise level as a function of two different kinds of flight situation variables. It was revealed that flight situation variables representing relations between flight elements had an effect on situation awareness. Working memory was found to play a critical role in integrating a variety of flight information from multiple sources. It was also revealed that flight situation variables representing the contents of flight elements had influence on situation awareness in flight. These results were explained in a theoretical framework of a construction-integration model to reveal the cognitive processes underlying situation awareness in flight.

Key words : Situation Awareness, Pilot Expertise, Cockpit Display

요 약 : 이 연구는 일반적인 인지이론을 조종사 기술의 범위로 확대시켜, 조종사가 얼마나 빠르고 정확하게 상황인식을 하는지를 제시문과 비행 장면 일치성 측정을 통해 알아보았다. 이 연구의 목적은 두 가지 측면의 변인에 따라 상황인식이 전문성의 영향을 받는지를 알아보는 것이다. 비행 요소 간의 관계를 나타내는 비행 상황 변인들과 비행 요소의 내용을 나타내는 비행 상황 변인들 모두 비행 상황인식에 영향을 주었다. 그리고 작업기억은 다양한 정보들을 통합시키는 데 결정적인 역할을 하는 것으로 나타났다. 이러한 결과는 비행 상황인식의 바탕인 인지적 과정을 나타내는 구조화-통합 모델의 이론적 틀 안에서 설명되어진다.

주제어 : 상황인식, 조종사 전문성, 조종실 계기

Overview of Situation Awareness

The concept of situation awareness has been identified as a major topic of interest in investigating human-machine systems (Endsley, 1995; Fracker, 1989; Metalis, 1993; Sarter & Woods, 1991). Within dynamic environmental circumstances in which a situation changes constantly, such as

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flight, air traffic control, and nuclear power plant control, it is required for operators to achieve and maintain a higher level of situation awareness by collecting and integrating a variety of information across time and space. Operators of human-machine systems have to update information about the current state of the system in order to perform their functions effectively and avoid a disastrous accident. For example, pilots have to continuously update the information of a current flight situation to fly safely and achieve a flight goal successfully. Similarly, air traffic controllers must have an overall understanding of the changing locations of aircrafts over time to avoid aircraft collision. In a dynamically changing environment, many decisions need to be made in a short period of time, and the loss of situation awareness, that is, the failure of maintaining situation awareness can cause a disastrous result.

Situation Awareness in Flight

In this study, We will focus on situation awareness achieved and maintained during flight. Flight is a very complex human-machine system in the sense that a variety of information from multiple sources is given to a pilot. Also, it is very dynamic because the current state of an aircraft is changing rapidly over time. Considering the dynamic nature of flight, which is rapidly changing across time, it is necessary to update current flight situation information in a short period of time.

Definitional and Methodological Issues in the Study of Situation Awareness

Two major issues may arise in regard to the investigation of situation awareness: how to define situation awareness and how to measure it. Researchers in this field have defined situation awareness in various ways by emphasizing different characteristics of situation awareness. Endsley (1990)'s definition of situation awareness includes three levels of information processes underlying situation awareness, each corresponding to the perception of situation elements, information integration, and projecting future states of the system. According to her definition, situation awareness includes an expectation of future states of the system as well as comprehension of the current state of an environment. Sarter and Woods (1991) viewed situation awareness as the integrated understanding of a situation by constructing a comprehensive and coherent situational representation which is constantly being updated. A closely related concept to this definition is a situational model (van Dijk & Kintsch, 1983) which is a mental representation of the situation described in the text.

Even though there is no consensus on among researchers on how to define situation awareness, many researchers agreed that situation awareness include not only the extraction of information from multiple sources in the environment, but also the integration of diverse sources of information to have an overall understanding of the current state of a system. Focusing on the integration mechanism underling situation awareness, it can be defined operationally as the overall understanding of the current state of an aircraft by integrating multiple sources of flight elements. In this research, we will use this operational definition of situation awareness in flight.

Considering the dynamic nature underlying situation awareness, it is difficult to find a single measure which can accurately evaluate the level of situation awareness maintained by an operator of a complex system. An accurate and reliable measurement technique is needed to provide a means of researching the components of situation awareness and investigating the impact of various factors in situation awareness. Although a variety of methodologies have been used to assess situation awareness, most of the measurements used to investigate situation awareness were subjective, such as self-rating (Selcon & Taylor, 1990) or a questionnaire (Endsley, 1988). Using these subjective measures, situation awareness was assessed by asking subjects about some situational questions in the middle of the task at hand. For example, Endsley (1988) had pilots perform some flight missions, and interrupted the task in the middle, and then asked some about the status of an aircraft at that point. Although this subjective measurement can show the level of situation awareness maintained by an operator, it cannot tell how fast they achieve situation awareness. To investigate situation awareness in a dynamically changing environment of complex systems, time-related characteristics of situation awareness have to be revealed. How fast a pilot acquires situation awareness is an important issue in aviation since time is a critical factor which can greatly affect a pilot's understanding of the current state of an aircraft.

Expertise in Situation Awareness

The role of expertise in human-machine system is an interesting topic in investigating the nature of situation awareness. Experience may enhance situation awareness by reducing the amount of mental resources required for specific tasks. The role of expertise in dynamic systems can be revealed by investigating important factors affecting the level of situation awareness, such as attention allocation mechanism, operator's knowledge base, and working memory capacity.

The efficient distribution of attention across multiple sources of information can alleviate the workload of the task, and may enhance situation awareness. Through eye-tracking experiments, the characteristics of eye scan patterns were revealed in regard to various flight missions to be completed (Kramer et al., 1994).

Another important factor to be considered in investigating situation awareness is the knowledge base of an operator. A well-organized knowledge base can provide a sufficient background for interpreting information perceived from multiple sources and constructing a coherent mental representation of a current situation. An experienced operator having a relevant knowledge base for the task may have a higher level of situation awareness by facilitating integration process. Also, resulting expectations about future states of a system based upon understanding of a current situation may facilitate perception and decision making processes because expectations can guide an operator on what to focus and what to do next in a given situation.

Working Memory and Situation Awareness

The role of working memory is also an important issue in situation awareness research. Sarter and Woods (1991) suggested that situation awareness is greatly limited by working memory and attention. If integration of a variety of situational information is a major cognitive process underlying situation awareness, the role of working memory in achieving and maintaining good situation awareness needs to be explained. Considering the limited capacity of working memory, which performs both computation and storage functions (Baddeley & Hitch, 1974), a consistent situation in which all situation elements are interdependent can be more easily understood than an inconsistent situation. Even though many researchers in this field (Endsley, 1995; Fracker, 1989; Sarter & Woods, 1991) agreed that working memory played a critical role in situation awareness, there was no empirical attempt to reveal the role of working memory in achieving and maintaining situation awareness.

A Cognitive Model-based Approach

In the area of situation awareness, there was no attempt to reveal the cognitive processes underlying situation awareness, although some researchers referred to the importance of perceiving information across multiple sources and integrating a variety of information to make a coherent mental representation of flight situation (Endsley, 1990; Endsley, 1995; Sarter & Woods, 1991). It was difficult to investigate the integration mechanism underlying situation awareness because there was no theoretical framework proposed to explain the cognitive processes underlying situation awareness. In this paper, we will present the construction-integration model as a theoretical framework for situation awareness, and provide some empirical data for validating this model as a general model of human cognition.

The construction-integration model (Kintsch, 1988) was originally proposed to explain certain phenomena of discourse comprehension. According to Kintsch (1988), text comprehension process is assumed to occur in two steps. In the first phase of 'construction', a text base is constructed from both linguistic input (incoming knowledge) and an existing knowledge base (background knowledge). The text base, a product of the first construction process, is in the form of an associative network of interrelated items. In the second phase of 'integration', this text base is integrated into a coherent whole via connectionist constraint-satisfaction search.

To account for cognitive processes underlying situation awareness in flight, the construction-integration theory of comprehension can be extended. Achieving and maintaining situation awareness in flight is thought of as a process to make a coherent mental representation of a flight situation. situation awareness in flight is assumed to occur in two stages. In the first phase of 'construction', an associative network of interrelated knowledge items which stand for flight-related concepts is constructed from information displayed in a cockpit instrument panel and an existing knowledge base of piloting skills. This initial network which is enriched, but incoherent, serves as the basis for the integration process. In this integration phase, activation spreads throughout the initial network to strengthen the connections between items which are consistent in regard to a current task context. Throughout this process, only context-relevant knowledge is selected. The limited capacity of working memory can play a critical role in this phase because of the dual-function of working memory, that is, storage and computation (Baddeley & Hitch, 1974). A variety of flight situation information is collected through multiple sources, such as altitude, airspeed, the rate of turning, power, etc. To acquire and maintain situation awareness, pilots need to integrate these multiple sources of data in order to have an overall understanding of the current state of an aircraft. Due to memory load, pilots might have difficulty in integrating all the information collected.

The role of expertise in flight can be explained in two different ways considering these construction and integration processes which are assumed as underlying mechanisms of situation awareness. Expert pilots might have a better understanding of a current flight situation because they have richly connected network of background knowledge. Otherwise, the better performance of expert pilots can be attributed to the better organized knowledge base which can reduce working memory limitations. In the domain of UNIX expertise, both sufficient requisite knowledge and limited capacity of working memory were identified as important factors to explain the role of expertise in the human-computer interaction domain (Doane et al., 1992; Sohn & Doane, 1996).

Research Goals

The goal of this study was to determine whether the differences in situation awareness in flight existed as a function of flight situation variables which were assumed to be important. We were also interested in how flight experience can affect situation awareness in flight as a function of these flight situation variables. For this purpose, we applied a theoretical framework of construction-integration model to explain cognitive processes underlying situation awareness in flight.

This study focused on the understanding of a current flight situation which should be achieved and maintained by a pilot during flight. For this purpose, knowledge base of piloting skills which was constructed in the previous research of Doane and her colleagues (as discussed in Fox et al., 1995) was used as the bases of diverse flight situations constructed in this experiment. Through the review of instrument flight manuals and by examining eye-scanning patterns revealed in a flight simulation study (Kramer et al., 1994), several flight situation variables were identified as important factors determining how fast and accurately pilots attain situation awareness in flight. Some situation variables represent the relations between flight elements, while other variables represent the contents of flight elements.

Flight Situation Variables Representing Relational Information

The number of flight elements, number of flight axes, and dependency were included in this category since they were assumed to have relational information about a flight situation. The process of computing relations between flight elements can be thought as the process of integrating multiple sources of information perceived. Assuming that this process occurs in working memory, the limited capacity of working memory can influence in achieving and maintaining situation awareness. We hypothesized that if information integration process is a major role in situation awareness, these situation variables representing relations can influence situation awareness.

Number of flight elements. The number of flight elements is a very simple concept which tells how many things regarding a flight situation are to be

Table 1. Examples of written statements for single and double elements

#elements	
Single	Altitude increasing by 500 fpm
Double	Turning to the left at a standard rate Airspeed 90 knots

identified (for examples, see table 1). This situation variable tells whether integration process is needed or not. We expected there would be no difference between expert and novice pilots in understanding a flight situation involving a single flight element. In the case of a flight situation composed of two flight elements, novice pilots were expected to show poorer performance in situation awareness than experts because of different working memory load.

Dependency and number of flight axes. The situations composed of two flight elements can be divided into different categories according to dependency and number of axis (for examples, see Table 2). To explain the notion of dependency, some flight dynamics knowledge has to be considered. A dependent situation implied that one flight element of interest is dependent upon other flight elements. For example, airspeed is closely related to RPM, and an altitude decrease may cause an airspeed increase. On the contrary, some situations can be thought of as independent in the sense that one flight element is not directly dependent upon another flight element. For example, current heading is not dependent on current altitude.

The notion of number of axis refers to how many axes are involved in a flight situation. Because two flight elements were included in a double-element situation, the possible number of axis could be one or two.

Table 2. Examples of written statements for independent/one axis, independent/two axes, dependent/one axis, and dependent/two axes

Dependency/ # axes	Independent	Dependent
One axis	Altitude 3400 feet Pitch up by 5 degrees	Turing to the right Bank right
Two axes	Power 3100 rpm Turning to the left	Altitude decreasing Airspeed increasing

Flight Situation Variables Representing the Contents of Information

As stated previously, to achieve and maintain situation awareness, it is required to integrate information from diverse sources. Before integration occurs, it is also needed to identify the contents of flight elements. In other words, the type of information contained in flight elements should be identified fast and accurately for higher level of situation awareness.

Some flight situation variables, such as type of axis, status vs. change information, and attribute vs. value information, were assumed to represent the contents of the flight elements. We hypothesized that some flight elements were identified faster than others if the former had more dynamic characteristics than the latter or if the former had more detail information to be identified than the latter. For example, change information is assumed to be more dynamic in nature than status information, and we expected that pilots were slower to comprehend changing situation than status situation.

Type of flight axis. The type of flight axis refer to the dimension which is related to the current

Table 3. Examples of written statements for longitudinal axis, horizontal axis, and vertical axis

Type of axis	
Longitudinal	Airspeed increasing
Horizontal	Bank right by 20 degrees
Vertical	Altitude decreasing

flight situation. The axis represented in a flight situation can be thought of as three-dimensional, each corresponding to longitudinal (airspeed-related), horizontal (heading-related), and vertical (altitude-related) axis (for examples, see Table 3).

Type of flight situation information. Even though a cockpit instrument panel includes a variety of flight information, it can be divided into several categories according to the characteristics of flight situation information (for examples, see Table 4). The first type of flight information to be identified by pilots is status vs. change information. To achieve a flight goal, some of the flight elements are required to be maintained at a specific level and other flight elements are required to be changed in a certain period of time. For example, if the goal is to increase altitude from 3000 feet to 3500 feet without any change on current level of airspeed (i.e., 120 knots) and heading (i.e., 360 degrees), pilots need to change the altitude to the desired value and maintain the airspeed and heading at the current level. We expected that situation awareness about change information would be more difficult than situation awareness about status information, because the aircraft' s changing situation may have more dynamic information than the status situation.

The second type of flight situation information to be identified by pilots is attribute vs. value

Table 4. Examples of written statements for status/attribute, status/value, change/attribute, and change/value

Type of information	Status	Change
Attribute	Bank right	Power increasing
Value	Heading 360 degrees	Altitude increasing by 300 fpm

information. In some cases, pilots need to simply check whether a current situation is higher or lower than normal (attribute information). In other cases, they need to check the exact value of a flight element to make sure the current situation is correct (value information).

Method

Participants

Eight pilots (six men and two women) participating in the pilot training program at the University of Illinois Institute of Aviation were recruited. They were either student pilots who were taking an Aviation 120 course, "Private Pilot, II" or flight instructors. A pre experimental questionnaire was administered to determine their flight experience. Participants were classified into two groups based upon level of expertise. Novice group was consisted of 4 student pilots. They ranged in age from 19 to 25 years and in total instrument flight time from 3 to 10 hours. The other group (expert) consisted of 4 pilot instructors. They ranged in age from 26 to 59 years and in total instrument flight time from 40 to 1,100 hours. Participants were paid $5 for the approximately 45 minutes of participation.

Apparatus & Materials

Each trial consisted of a written statement followed by a cockpit display. The written statement described a flight situation which included either a single flight element or double flight elements. A single flight element situation consisted of one line of text (i.e., "Airspeed 90 knots"), while double flight elements situation consisted of two lines of text (i.e., "Turning to the right" and "Pitch down"). These written statements were shown on the center of the screen.

A cockpit display showed the current status of an aircraft via seven primary instruments. In order to overcome the limitation of showing static pictures of cockpit instruments in which information is unavailable about change in progress for airspeed, power, and pitch/bank, highlighting techniques were introduced in this experiment. That is, to indicate the change in progress, the appearance of the airspeed indicator, tachometer, and ADI was modified by highlighting. The most highlighted point represented the current value of a flight element and the less highlighted points represented prior values. A total of 176 cockpit displays representing 176 different flight situations were constructed.

Procedure

Prior to starting the experiment, all participants filled out a questionnaire regarding their flight experience (total flight hours, aircraft type flown, current flight hours, etc.). Participants were classified in two groups (expert and novice group) based upon this information.

The participants were seated and then given instructions on what tasks would be required of them during the experiment. After reading the instructions, participants completed eight practice trials with feedback regarding their responses. Upon completion of the practice trials, participants were given experimental trials. Feedback was not given during the experimental trials. The stimuli, written statements followed by cockpit displays, were presented in 4 blocks, where each block consisted of 44 trials with 22 consistent judgments and 22 inconsistent judgments. Three randomized block orders were constructed, and participants were randomly assigned to one of the three randomized block orders. Participants made consistency judgments for a total of 176 trials. The whole experiment lasted approx. 45 minutes.

Each trial consisted of two screens. The first screen contained a written statement describing a flight situation, and the second screen contained a cockpit instrument panel showing the current status of an aircraft. Participants first read a written statement describing some aspect(s) of flight situation. They were asked to press the space bar when they understood the meaning of the written statement. When they pressed the space bar, the first screen of a written statement disappeared and the next screen of a cockpit display appeared. They were then asked to judge the consistency of the written statement and the cockpit display (i.e., does the cockpit display accurately represent the flight situation described in the written statement?). They were asked to press the key marked "C" if they believed the written statement and the display were consistent, or press the key marked "I" if they believed the written statement and the display were inconsistent. Both accuracy and speed of response were emphasized. The computer gave participants a beep when they pressed a key it could not process. When participants typed ahead, the computer gave them a beep and showed them a message of "Please don' t type ahead" on the top of the screen. Once they determined the consistency, the next trial was presented with an inter-trial interval of 1 second. The type of key they pressed, response time for reading a written statement, and a response time for consistency judgment were all recorded.

Results and Discussion

There were 176 problems, each representing different states of an aircraft according to two groups of flight situation variables. The first group of flight situation variables included the number of flight elements (single vs. double), dependency (independent vs. dependent), and number of flight axes (one vs. two). The second group of flight situation variables included type of axis (longitudinal, horizontal and vertical), and two different types of flight information (status vs. change and attribute vs. value). Twenty four flight situations which contained pitch or bank change information were excluded because they were difficult to understand. Therefore, a total of 152 problems were analyzed. Data analyses were conducted on the different groupings based upon one flight situation variable or combined variables of interest. Table 1 through 4 show examples of written statements, each corresponding to the grouping based upon number of flight elements, dependency X number of flight axes, type of axis, and two different types of flight situation information.

Three different measures were obtained for each problem, one accuracy data and two response latency data. We measured accuracy of consistency judgment between a written statement and a cockpit display. Also, we measured reading time representing the amount of time taken to comprehend a written statement describing the current state of an aircraft. Another measure was consistency judgment latency which represented the amount of time taken to make a consistency judgment between a written statement and a cockpit display.

Overall, consistency judgment accuracy in this task was very high (mean accuracy = 0.96), which means most situation awareness problems constructed in this experiment were not difficult to understand. There was no significant difference in consistency judgment accuracy between expert and novice groups. It suggests that even novice pilots had enough requisite flight knowledge for this task. Mean reading time for written statements was 2.63 s, and Mean consistency judgment latency was 2.25 s. Inspection of the means and standard deviations for both groups of pilots and two levels of number of flight elements indicated that there were some outliers in the response latency data (reading time and consistency judgment latency). Prior to statistical analysis, response latency data which were deviant from the mean by 3.5 standard deviation were cut off to delete the extreme responses.

Consistency Judgment Accuracy

Number of Flight Elements. A 2 x 2 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (number of elements) was conducted on consistency judgment accuracy. The aim was to establish whether differences in consistency judgment accuracy existed between expertise

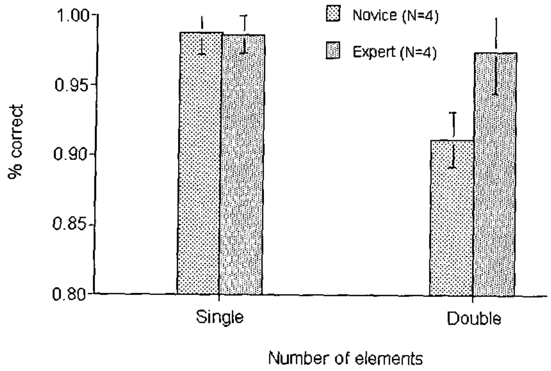

Figure 1. Accuracy as a function of number of elements.

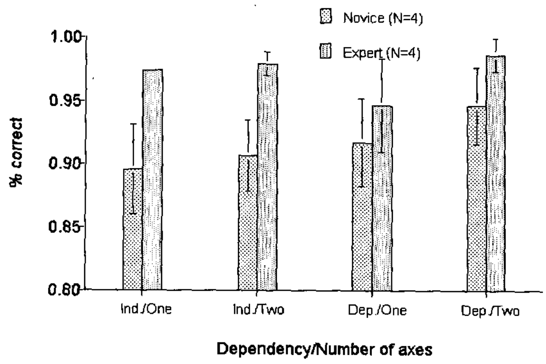

Figure 2. Accuracy as a function of dependency and number of axis.

groups (novice vs. expert) as a function of number of flight elements (single vs. double).

Figure 1 shows mean consistency judgment accuracy for two expertise groups as a function of the number of flight elements. A significant main effect of number of flight elements was found, $F(1, 6) = 42.84$, $p < .001$. It means consistency judgment for a single flight element was more accurate than consistency judgment for double flight elements. Even though there was no main effect of expertise groups, significant interaction effect of expertise level and number of flight elements was found, $F(1, 6) = 21.77$, $p < .001$. Expert pilots' performances (i.e., mean consistency judgment accuracy) were not affected by the number of flight elements, but novice pilots' performances dropped as the number of flight elements increased. These results can be explained by working memory limitations. Assuming that both expert pilots and novice pilots have enough requisite knowledge for this task, the difference on double flight-element situations between expertise level can be attributed to the different memory load they had. It can be thought that the knowledge base of expert pilot is better organized and it can reduce the memory load while integrating two or more flight elements.

Dependency and Number of Flight Axes. In the case of double flight elements problems, flight situations can be classified as four different types (independent/one axis, independent/two axes, dependent/one axis, and dependent/two axes). A 2 x 2 x 2 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (dependency) and the third variable (number of flight axes) was conducted on consistency judgment accuracy. The aim was to determine whether differences in consistency judgment accuracy existed between expertise (novice vs. expert), dependency (independent vs. dependent), and number of flight axes (one axis vs. two axes).

Figure 2 shows mean consistency judgment accuracy for two expertise groups as a function of dependency and number of flight axes. A significant main effect of expertise level was found, $F(1, 6) = 6.21$, $p < .05$. Expert pilots' consistency judgment were more accurate than novice pilots'. There was no significant main effect of number of flight axes suggesting that pilots' performance (consistency judgment accuracy) was not affected by number of flight axes. A test of the interaction of expertise level and dependency approached a significance level,

$F(1, 6) = 3.99$, $p < .10$. This suggests that the dependency in a flight situation differentially influence situation awareness as a function of subject expertise. Novice pilots' performance (i.e., consistency judgment accuracy) was more affected by dependency in a flight situation than expert pilots' performance. These data also suggest that expert pilots showed good performance for both independent and dependent flight situations, however, novice pilots showed better performance for dependent flight situations than for independent flight situations.

Reading Time

Number of Flight Elements. A 2 x 2 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (number of elements) was conducted on reading time. The aim was to establish whether differences in reading time existed between expertise groups (novice vs. expert) as a function of number of flight elements (single vs. double).

Figure 3 shows mean reading time for two expertise groups as a function of number of flight elements. A significant main effect of number of flight elements was found, $F(1, 6) = 230.30$, $p < .001$. It means that reading time for single flight element was faster than reading time for double flight elements. Neither significant main effect of expertise group nor interaction effect of expertise and number of flight elements were found.

Dependency and Number of Flight Axes. A 2 x 2 x 2 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (dependency) and the third variable (number of flight axes) was conducted on reading time. The aim was to determine whether differences existed between expertise (novice vs. expert), dependency (independent vs. dependent), and number of flight axes (one axis vs. two axes).

Figure 4 shows mean reading for two expertise groups as a function of dependency and number of flight axes. Even though there was no significant main effect of expertise level, a significant main effect of dependency was found, $F(1, 6) = 4.45$, $p < .08$. It suggests that pilots spent more time comprehending dependent flight

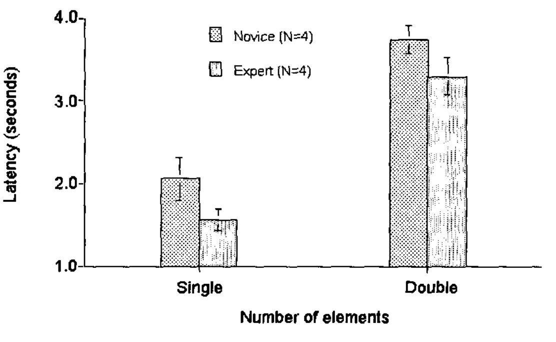

Figure 3. Mean comprehension latency as a function of number of elements.

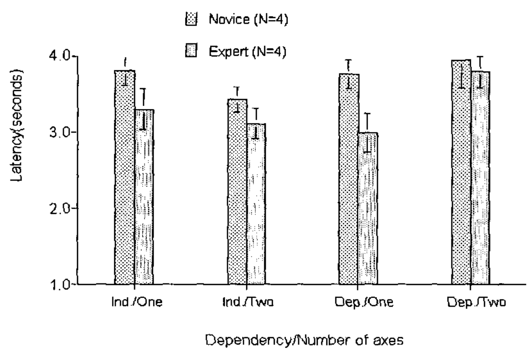

Figure 4. Mean comprehension latency as a function of dependency and number of axes.

situations than independent flight situations. Another result of interest is an interaction effect between dependency and number of flight axes, $F(1, 6) = 13.99$, $p < .001$. It means that pilots spent more time in comprehending a flight situation which was dependent and composed of two flight axes than any other flight situation (independent/two axes, dependent/one axis, and dependent/two axes). Flight elements are interrelated each other in a dependent situation, but not in independent situation. Slower response time for dependent situations suggests that pilots tried to make a coherent mental representation of a current state of an aircraft.

Type of Flight Axis. To determine whether situation awareness in flight is influenced by expertise level and type of axis, a 2 x 3 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (type of axis) was conducted on reading time.

Figure 5 shows mean reading time for two expertise groups as a function of type of axis. A significant main effect of type of axis was found, $F(1, 6) = 103.68$, $p < .001$. An inspection of the data for three different types of axes indicates that pilots were fastest to comprehend a flight situation of longitudinal axis, and slowest to comprehend a flight situation of vertical flight axis.

Type of Flight Information. To determine whether situation awareness in flight is influenced by type of flight information, a 2 x 2 x 2 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (status vs. change) and on the third variable (attribute vs. value) was conducted.

Figure 6 shows mean reading time for two expertise groups as a function of status vs. change information and attribute vs. value information. A significant main effect of status vs. change information was found, $F(1, 6) = 54.07$, $p < .001$. It means that pilots were faster to comprehend status information than change information. There was also a significant main effect of attribute vs. value information, $F(1, 6) = 20.48$, $p < .05$. It suggests that pilots spent more time in comprehending value information than attribute information. A significant interaction effect of expertise level and status vs. change information was found, $F(1, 6) = 3.92$, $p < .10$. It suggests that expert pilots were more affected by status vs. change information

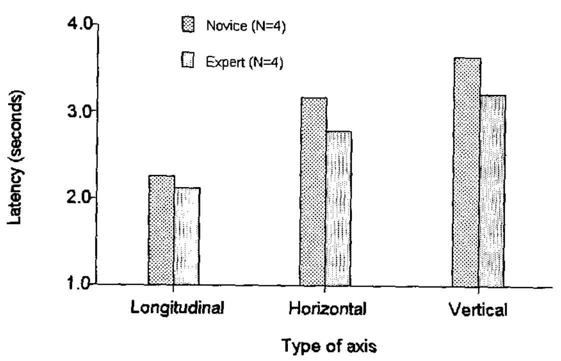

Figure. 5. Mean comprehension latency as a function of type of axis

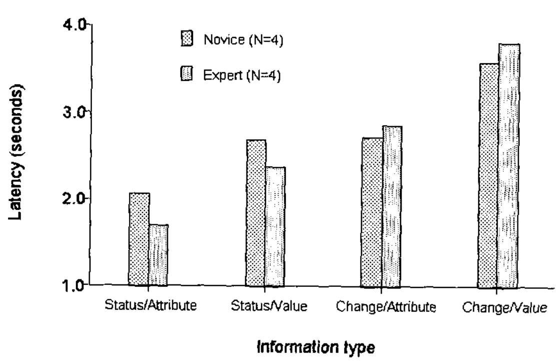

Figure. 6. Mean comprehension latency as a function of information type

than novice pilots.

Consistency Judgment Latency

Number of Flight Elements. A 2 x 2 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (number of elements) was conducted on consistency judgment latency. The aim was to establish whether differences in consistency judgment latency existed between expertise groups (novice vs. expert) as a function of number of flight elements (single vs. double).

Figure 7 shows mean consistency judgment latency for two expertise groups as a function of number of flight elements. A significant main effect of number of flight elements was found, $F(1, 6) = 78.82$, $p < .001$. It means that consistency judgment for single flight element was faster than consistency judgment for double flight elements. There were neither significant main effect of expertise group nor interaction effect.

Type of Flight Information. To determine whether situation awareness in flight is influenced by type of flight information, a 2 x 2 x 2 mixed factorial analysis of variance (ANOVA) with repeated measures on the second variable (status vs. change) and the third variable (attribute vs. value) was conducted on consistency judgment latency.

Figure 8 shows mean consistency judgment latency for two expertise groups as a function of status vs. change information and attribute vs. value information. A significant main effect of attribute vs. value information was found, $F(1, 6) = 7.71$, $p < .05$. It suggests that pilots spent more time in making consistency judgment for attribute information than for value information. There was also a significant interaction effect of status vs. change information and attribute vs. value information, $F(1, 6) = 24.28$, $p < .001$. Pilots were slowest to make a consistency judgment for change/attribute flight information than any other types of flight information (status/attribute information, status/value information, and change/value information).

General Discussion

The goal of this research was to investigate the

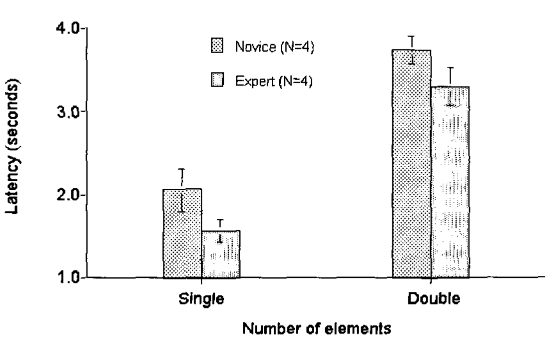

Figure. 7. Mean decision latency as a function of number of elements

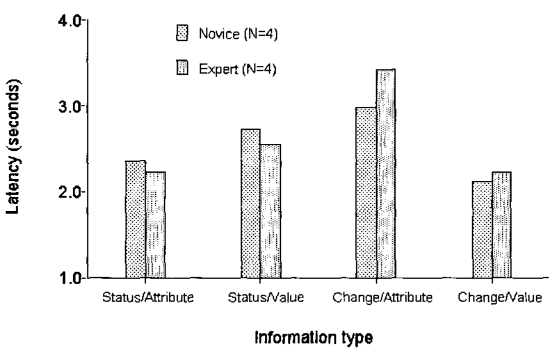

Figure. 8. Mean decision latency as a function of information type

role of expertise in situation awareness in flight in regard to two different flight situation variables. To assess situation awareness reliably and objectively, it is needed to measure how fast and accurately pilots attain situation awareness. For this purpose, we presented a written statement describing a flight situation followed by a cockpit display showing a current state of an aircraft. The subjects were then asked whether they were consistent or not. By doing this, we could get a measure of accuracy which represents the level of flight situation awareness maintained by pilots. Also, we could get two response latency measures (reading time and consistency judgment latency) which represent how fast pilots achieve situation awareness in flight. To test the role of working memory in situation awareness in flight, we manipulated three flight situation variables which represent relational information between flight elements. The data showed that the number of flight elements and the number of flight axes had influence on situation awareness. It suggests that integration process is a major role in achieving and maintaining situation awareness. In addition, situation awareness was found to be affected by expertise level. The other situation variables representing the contents of flight information affect situation awareness in flight. It suggests that fast and accurate identification of flight elements are also important to situation awareness.

Limitations of this research

This experiment used a static display of a cockpit instrument panel which cannot show the changing information occurred in a usual flight situation. Even though we used highlighting techniques to represent changing information for some flight elements, it is not sufficient to represent a dynamically changing environment of an aircraft. Another problem of this research is the small number of subjects. we had only four expert pilots and four novice pilots, and this is not enough to reveal the differences between expert and novice pilots.

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