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상황인식 민감도에 있어서의 전문성 효과 : 정보처리 접근법

Expertise Effects in Situation Awareness Sensitivity : Information Processing Approach

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Abstract : The role of memory is viewed as central to developing and maintaining flight situation awareness (SA). The present research examines constituent memory processes that underlie flight SA sensitivity as a function of pilot expertise. In Experiment 1, pilot memory for different forms (spatial or verbal) of cockpit situational information was tested immediately after presentation of the information (immediate recall) or after 30-s delay filled with an intervening task (delayed recall). In Experiment 2, pilot SA sensitivity was examined and correlated with memory measures obtained in Experiment 1. Results suggest that an expertise effect occurs in delayed recall but not in immediate recall and that memory representation of situational information required to develop high levels of SA sensitivity varies as a function of expertise. Theoretical accounts of results are discussed in the context of psychological theories of expertise.

Key words : Situation Awareness, Expertise, Memory

요 약 : 기억은 상황인식을 개발하고 유지하는 데 중요한 역할을 한다. 본 연구에서는 비행상황 인식의 민감도에 영향을 주는 기억과정들이 조종사의 전문성 정도에 따라 어떻게 다른지를 조사하였다. 실험 1에서는 조종사가 상황정보를 회상하기 위해 사용하는 여러 기억과정들을 비교하였다. 즉, 조종실 계기판에 제시되는 상이한 형태(공간적 및 언어적)의 상황정보에 관한 조종사의 기억을 즉각회상과 지연 회상법으로 평가하였다. 실험 2에서는 조종사의 상황인식 민감도를 측정하였고, 그 민감도와 실험 1에서 수집한 여러 회상기억 측정치들과의 상관관계를 조사하였다. 두 실험결과를 요약하면, 전문성 효과가 상황정보의 활동기억보다는 장기기억에서 나타났고, 상황인식 민감도를 높이는 데 요구되는 상황정보의 기억표상이 전문성 정도에 따라 달랐다. 실험결과의 이론적 설명이 심리학의 전문성 이론을 중심으로 논의되었다.

주요어 : 상황인식, 전문성, 기억

1. Introduction

1.1 Definition of Situation Awareness

In 1997, a Korean passenger airplane flying to Guam crashed, killing 228 people on board. Aviation researchers suggested that the accident was due to a failure in the pilot's ability to develop and maintain an awareness of the flight situation.

Situation awareness (SA) is a term that emerged from aviator and air traffic controller characterization of incidents and accidents as being due to failure to develop and maintain an awareness of the flight situation (Sarter & Woods, 1991, 1995). The term SA has been highlighted in the aviation domain because of its prominent role in flight operations. Analyses of existing data bases point to

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a loss of SA as an important precursor to performance failure. For example, in a review of National Transportation Safety Board (NTSB) aircraft accident reports across a 4-year period, 88% of the accidents attributed to human error involving SA as a major causal factor (Endsley, 1995a).

Although it has been considered an essential prerequisite for the safe operation of aircraft, the use of the term SA is inconsistent overall in the domain of aviation. Its use is most often based on an intuitive understanding and a commonly accepted definition is missing. Some researchers use the term to describe the product or state of SA at a given point in time, while others use the term to describe a process of constructing or updating the product or state of SA (e.g., see Endsley, 1995b; Jones & Endsley, 2000; Sarter & Woods, 1991, 1995).

While there is no consensus in the definition of SA cited in the aviation psychology literature, aviation psychologists have focused on the cognitive components of SA because of the increasingly cognitive nature of the tasks operators should perform (Durso & Gronlund, 1999; Endsley & Garland, 2000; Wickens, 1999). The spirit of most definitions of SA can be incorporated into Endsley's information processing view (Durso & Gronlund, 1999; Wickens, 1999). Endsley's (1995b) view defines three levels of SA in terms of component cognitive processes. The first level of SA involves perceiving environmental elements such as other aircraft, terrain, system status and warning lights. The second level involves information integration, a process of activating long-term memory (LTM) knowledge structures (e.g., schemata, scripts, mental models, etc.) in order to organize the perceived situation elements into meaningful and recognizable configurations. The third level includes processes that enable projection of future flight status. This third level of SA uses the goal-relevant activated knowledge structures formed in the second level of SA to predict the status of the aircraft.

The accuracy of SA is a function of activating LTM knowledge structures that facilitate the integration of environmental information and result in a coherent interpretation of the current and future flight status (i.e., the situation model). Recent research suggests that the integration of environmental information takes place in working memory (WM) (e.g., Sohn & Doane, 2002). In summary, SA in Endsley's view involves cognitive processes related to a complex cognitive activity, and these cognitive processes dictate whether the resulting level of awareness will benefit pilot performance.

1.2 Researching Memory Components of SA

In their recent review article, Durso and Gronlund (1999) detail the extent of the definitional problem, and explicate the need for research on the cognitive components of SA (also see Flach, 1995). In fact, they state, Empirical study of the constituent cognitive processes of SA is critical to making it a viable construct. Prior to describing the present research, it is important to explicate the need for a componential analysis.

The expected value of a componential approach to researching flight SA depends upon the relationship between the configural whole that is the resulting level of awareness and the componential parts or cognitive processes that are central to achieving SA (Endsley, 1995b). Flight situation awareness is by definition configural, requiring the comprehension and integration of multiple dynamically changing elements in the environment (e.g., Adams, Tenney, & Pew, 1995). If the configural whole were greater than the sum of the parts then a componential analysis of the processes that enable SA would have limited theoretical and practical utility.

However, many SA researchers suggest that understanding component processes is crucial to understanding SA (e.g., Durso & Gronlund, 1999; Endsley, 1995b; Sarter & Woods, 1991). Adams, Tenny, and Pew (1995) suggest that componential analyses will address the practical need for the ability to predict failures in SA. For example, recent research suggests that componential analyses of WM and LTM processes (e.g., Ericsson & Kintsch, 1995; Sohn & Doane, 1997) are useful in predicting failures in SA (e.g., Sohn & Doane, 2002; see Durso & Gronlund, 1999 for a complete review of additional componential research).

In summary, there is evidence to suggest that researching the componential parts of SA will further our understanding of the configural whole that is the resulting level of awareness. In addition, more recent evidence suggests that componential analyses are useful for predicting SA failures (e.g., see Endsley & Garland, 2000).

1.3 Present Research

Although the componential analysis of SA is critical to diagnose pilot SA problems, few studies have taken this importance seriously. In a study of U. S. Air Force F-15 pilots, Caretta, Perry, and Ree (1996) examined psychological determinants of SA. Caretta et al. used cognitive, psychomotor, and personality factors to predict the supervisory and peer ratings of SA. They found that only the cognitive factors such as verbal and spatial WM, spatial reasoning, and divided attention were the reliable predictors of SA after controlling for the effects of pilot expertise. Whereas Caretta et al. (1996) used cognitive factors that were solely based on WM as predictors of SA, Stokes, Kemper, and Kite (1997) used LTM-based knowledge representations as well as WM-based information processing abilities to predict decision-making optimality on a simulated flight situation. Stokes et al. found that LTM-based knowledge representation measures and WM-based spatial memory measures were predictive of flight decision making, though the former measures were the better predictors for expert pilots. These previous studies suggest that the role of memory processes is important in SA and that constituent memory processes central to SA vary with pilot expertise.

Considering the importance of memory processes that varies with expertise, the present research places its emphasis on the effects of expertise in memory processes of SA. The objective of the present research was to advance our understanding of the memory components of flight SA by examining the relationship between memory and sensitivity measures of SA. To accomplish this objective, the present research consisted of two experiments. Experiment 1 examined novice-expert differences in ability to access WM and LTM. Experiment 2 examined the roles of memory components in SA sensitivity as a function of expertise. The methods and results of each experiment will be detailed in the subsequent sections.

2. Experiment 1

2.1 Goal and Design

The goal of Experiment 1 was to examine pilot access to WM and LTM as a function of expertise. As a method to measure pilot access to WM and LTM, we used a situation recall task, which is analogous to the chess experiment by Charness (1976). Charness compared chess players' memory for chess positions immediately after they had viewed the positions or after a 30-second delay filled with an interfering task. In this experiment, cockpit displays were used instead of chess positions.

Specifically, we employed a 2×(2×2) mixed factorial design with a between-participants variable of pilot expertise (novice, expert) and within-participants variables of situation modality (spatial, verbal) and recall delay (immediate, delayed). The cockpit situations were represented in either spatial or verbal form to examine the effect of presentation modality on pilot ability to construct an accurate mental representation of cockpit situation. The spatial form included a pictorial snapshot of actual cockpit instruments, while the verbal form was a written description of instrument indications. Pilots' memory for a cockpit situation was tested immediately after they were presented with situational information or after a 30-s delay filled with an intervening task. The intervening task was considered to clear short-term storage of the earlier presented information.

2.2 Methods

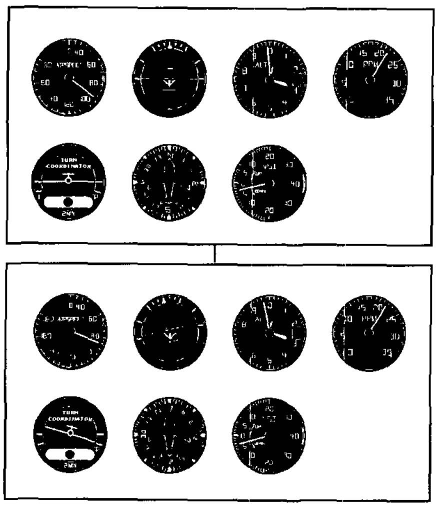
2.2.1 Participants

Forty student and instructor pilots participated in this experiment. As a result of pre-experimental questionnaire data analysis, participants were classified as novices (n=20) with on average total flight time of 70 hours or experts (n=20) with on average total flight time of 1460 hours (For additional questionnaire and classification details, see Doane & Sohn, 2001).

2.2.2 Materials and procedure

Participants' task on each trial was to view a sequence of two cockpit situations presented on the screen and recall the situational information. Participants were presented either with pictorial cockpit snapshots as shown in Figure 1a (spatial stimuli) or verbal lists that described cockpit situations as shown Figure 1b (verbal stimuli). The situations represented consecutive states of the aircraft in terms of the seven instrument indications typical in private aircraft. Participants were allowed to view the situational stimuli for 40 seconds. The

(a) Cockpit Snapshots



(b) Cockpit Descriptions

Airspeed: 105 kt
Bank: 15 ° to the left
Pitch: 0.5 dot above
Altitude: 4200 ft
Power: 2400 rpm
Rate of turn: Standard to the
Heading: 270 °
Rate of climb: 0 ft/min

Airspeed: 95 kt
Bank: 0 °
Pitch: 1 dot above
Altitude: 4220 ft
Power: 2300 rpm
Rate of turn: 0
Heading: 260 °
Rate of climb: 200 ft/min

Fig. 1. Pairs of example (a) cockpit snapshots and (b) cockpit descriptions used for situation recall tasks

situation presented on top of the screen showed the initial state of an airplane and the situation presented on bottom of the screen showed an approximated 5-s later state of the airplane in actual flight. The 5-s flight interval between the two snapshots was long enough to indicate a noticeable amount of change in cockpit displays. After 40 seconds of presentation, the stimuli disappeared and participants had to recall the flight situation.

For the spatial situation trials, participants reconstructed the situation by manually filling in the indications of display instruments on a blank cockpit frame sheet of paper. For the verbal situation trials, they reported aloud the description of display indications to the experimenter. Participants were asked to recall the value indications that were presented in either the top or bottom situation, and the choice of situation to be recalled was randomly selected.

In the intervening task for the delayed-recall trials, participants counted backward by threes as fast as possible during the retention interval. For example, a prompt such as "Count backward by 3: 528" was presented on the screen following the disappearance of the cockpit snapshots and participants counted backward by threes from 528: 525, 522, 519, and so on. This intervening task was devised to interrupt maintenance and computation of the display indications in WM. Participants performed immediate-recall trials, followed by delayed-recall trials with spatial stimuli on Day 1 and those with verbal stimuli on Day 2.

2.3 Results and Discussion

2.3.1 Scoring correct recall responses

Responses were scored as correct if they matched exactly corresponding indications. Participant

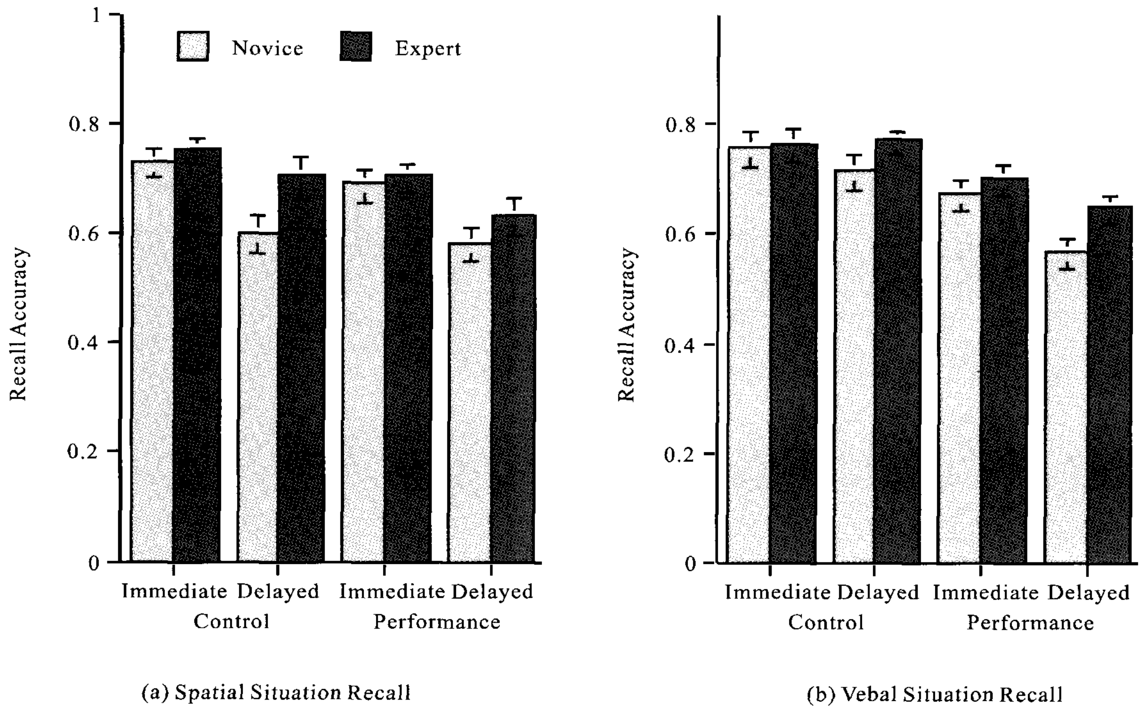


Fig. 2. (a) Spatial situation and (b) verbal situation mean recall accuracy for novices and experts as a function of flight element (control, performance) and recall delay (immediate, delayed)

responses for pitch, bank, and power ("control elements") indicated by attitude indicator and tachometer and for airspeed, heading, altitude, and rates of climb and turn ("performance elements") indicated by airspeed indicator, heading indicator, altimeter, vertical speed indicator, and turn coordinator were scored separately. Control elements indicate input settings of control movements whereas performance elements indicate the behavior of the aircraft resulting from control movements (Dogan, 1999).

2.3.2 Recall accuracy

Figure 2 shows spatial and verbal situation mean recall accuracy for novices and experts as a function of flight element (control and performance) and recall delay (immediate and delayed). As the figure suggests, there was a loss in recall for both groups when delayed by an intervening task, $F(1, 38)=31.57$, $MSE=0.012$, $p<.01$, but less loss in recall for experts, $F(1, 38)=4.97$, $MSE=0.012$, $p<.03$. Overall both groups showed higher recall accuracy for control elements than for performance elements, $F(1, 38)=70.71$, $MSE=0.006$, $p<.01$. There were no effects of situation modality, expertise×flight element interaction, or expertise×situation modality interaction, all $Fs<2$.

In summary, novice-expert differences occurred not in immediate recall but delayed recall of situational information. This expertise effect suggests that expert pilots are able to encode situational information in accessible form in LTM more efficiently than novice pilots.

3. Experiment 2

3.1 Goal and Design

The goal of Experiment 2 was to examine novice and expert pilot performance on a SA task and determine whether memory measures are valid indicators of SA. Of particular interest was to determine which memory measures are the most valid indicators of SA.

Following the definition of SA from the information processing view, the task posed to participants in the present research was designed to reflect the ability to perceive information across multiple sources, to integrate a variety of perceived information to make a coherent mental representation of the current flight situation, and to project the status of the aircraft in the near future (Dominguez, 1994; Endsley, 1995b). Specifically, participants viewed consecutive screens that showed a goal description and two consecutive cockpits and then judged whether an aircraft depicted by the consecutive cockpit snapshots would reach the specified goal state in the next 5

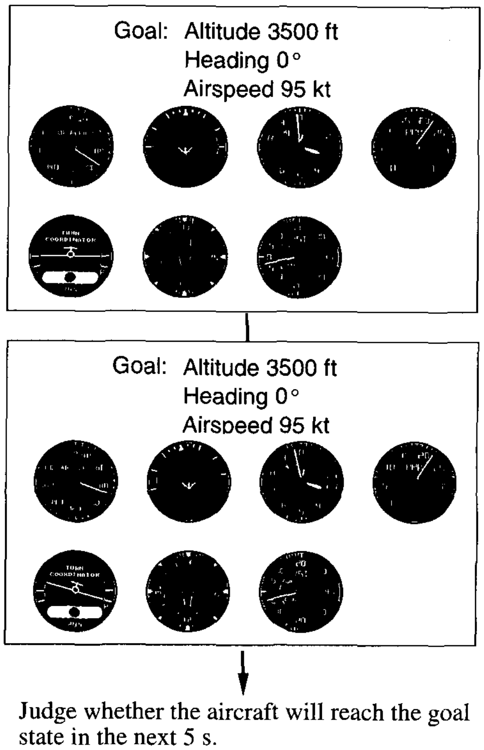


Fig. 3. An example trial of an SA task

s (see Figure 3). (The details of task materials and procedures are provided in the methods section.) To successfully perform this task, participants must perceive changes in flight situation elements across various instruments (e.g., status and changes in altitude, heading, airspeed), interpret and understand their meaning with respect to the goal (e.g., I am currently below my desired airspeed, etc.), and predict their future implications given the goal state in mind (e.g., given my current state and rates and directions of change, I am headed toward my desired flight status).

3.2 Method

3.2.1 Participants

All participants in Experiment 1 also participated in Experiment 2 and they remained in the expertise groups designated in Experiment 1.

3.2.2 Materials and procedure

As previously stated, a SA trial was composed of consecutive screens that showed a goal description and two consecutive cockpits (see Figure 3). The goal description indicated the desired state that an aircraft should reach in the near future (i.e., in approximately 5 s) on the three flight performance elements (e.g., "Altitude 3500 ft, Heading 0, Airspeed 95 kt").

The first screen displayed the goal description on top of the screen and right below it the cockpit snapshot that depicted the initial flight situation (at time 1) for 20 s, at which time the first cockpit snapshot disappeared and the second cockpit snapshot appeared. The goal state description remained on top of the screen. The second snapshot depicted the "current" state of the aircraft (at time 2) following changes caused by control movements (not specified to the participants) executed at time 1. This second snapshot depicted the state of the aircraft approximately 5 seconds following the status depicted in the first snapshot. The 5-s flight interval between the two snapshots was sufficient to indicate a noticeable amount of change in cockpit displays of aircraft status. The second snapshot remained on the screen until participants pressed a response key, at which time the goal description and the second snapshot disappeared.

Participants were asked to determine if the aircraft depicted in the cockpit snapshots would achieve the goal initially specified in the next 5 seconds without further control movements. In essence, they had to mentally predict the state of the aircraft in the next 5 seconds with the constraint that no further control movements would be applied. The participants indicated whether the aircraft was moving in a manner consistent with achieving the goal, or in a manner inconsistent with achieving the goal by pressing the key marked "C" for consistent or "I" for inconsistent. Inconsistent trials were created by manipulating one of three flight elements (i.e., altitude, heading, airspeed) depicted in the second snapshot to render the current (time 2) flight situation inconsistent with the specified goal. The entries of the consistency judgment were recorded by the computer.

3.3 Results and Discussion

To measure pilot SA performance, we used the accuracy of consistency judgments to calculate hits (correct judgments for consistent stimuli) and false alarms (incorrect judgments for inconsistent stimuli) and used these to determine pilot judgment sensitivity (d') and response bias.

3.3.1 Pilot SA sensitivity

We analyzed accuracy data in the context of signal detection theory to determine how sensitive participants were to discriminating between consistent and inconsistent stimuli (Green & Swets, 1966). To determine the observer sensitivity of pilot consistency judgments, correct judgments for consistent stimuli and incorrect judgments for inconsistent stimuli represented hits and false alarms in d' calculations, respectively. Following procedures outlined in Green and Swets (1966), bias scores were also calculated to determine if the group differences are influenced by different criteria novices and experts used for making consistent or inconsistent judgments.

The resulting judgment sensitivity (d') was higher for experts (M=1.70) than that for novices (M=1.25), $F(1, 38)=7.23$, $MSE=0.279$, $p<.01$. However, there was no difference in judgment bias between the two groups, $F<1$. These results suggest that the SA task differentiated between novices and experts and the group performance differences were due to judgment sensitivity, not due to judgment criterion differences. Because judgment sensitivity differed between novices and experts, we used this measure to correlate with the memory components measured in Experiment 1.

3.3.2 Memory measures and SA

The major question of interest was which memory measures are valid indicators of SA performance. To address this question, correlation analyses were conducted using memory and SA measures. Table 1 shows correlation between each of memory measures and SA judgment sensitivity. Overall, delayed-recall measures were more valid indicators of SA performance for both expertise groups than immediate-recall measures. As shown in the table, the role of specific memory measures varied as a function of expertise. The delayed recall of verbal situations correlates highly with SA sensitivity for novices, whereas the delayed recall of spatial situations correlates highly with SA sensitivity for experts. One explanation for this result is that the verbal cockpit situation might be easier to translate into a coherent representation of the flight situation for novices who have fewer exposures to the actual spatial cockpit stimuli than for experts.

Table 1. Correlation between memory measures and SA sensitivity (d') for novices and experts

Memory Measures	Novices	Experts
Spatial Situation		
Immediate Recall (Overall)	.02	.20
Control Element	-.18	.29
Performance Element	.10	.14
Delayed Recall (Overall)	.05	.47*
Control Element	-.06	.51*
Performance Element	.02	.37
Verbal Situation		
Immediate Recall (Overall)	.13	.10
Control Element	.06	-.08
Performance Element	.14	.17
Delayed Recall (Overall)	.48*	.02
Control Element	.26	-.08
Performance Element	.50*	.14

*$p<.05$

Focusing on separation of flight elements into control and performance groups, Table 1 suggests that verbal memory of performance elements is indicative of novice SA performance, whereas spatial memory of control elements is indicative of expert SA performance. This may occur because novices are more familiar with verbal descriptions of performance elements (e.g., "altitude 3000 ft.") than control elements (e.g., "pitch 2 dots above the horizon") while experts are more familiar with spatial configurations of control displays central to their instrument scanning than with those of performance displays.

In summary, pilot ability to access LTM rather than WM was the valid indicator of SA performance for both expertise groups. However, specific memory representations related to SA performance varied with pilot expertise. Verbal memory of performance information is important for novice SA, whereas spatial memory of control information is important for expert SA.

4. General Discussion

The present research represents a theoretical contribution to understanding of pilot expertise in situation memory and awareness. Our findings serve to emphasize the importance of LTM stores for SA and the novice-expert differences in LTM representations of SA information. Although LTM stores may take many forms, the stores in the form of mental models or schemata are hypothesized to play a major role in achieving SA (Doane & Sohn, 2002; Durso & Gronlund, 1999; Endsley, 1995b). With experience, pilots develop internal models of the cockpit instruments they operate and the environments in which they operate. These models help direct limited attention to relevant aspects of the situation, and provide a means of integrating information and generating projection of future flight states without loading WM. Without such a mechanism, expert pilots may not be able to perform a SA task with ease. Klein (1989) provides a more detailed description of how mental models and schemata may be used for naturalistic decision making such as flight SA.

In Klein's recognition-primed decision model, critical cues in the environment may be matched to mental models or schemata of cockpit system states to indicate prototypical situations that provide instant situation classification and comprehension. Scripts of the proper actions to take may be attached to these situation prototypes. In many instances, schemata of prototypical situations may be associated with scripts to produce single-step retrieval of actions from memory, thereby providing for rapid decision making. In this sense, the use of mental models in achieving SA is considered to be dependent on pilot ability to pattern match between critical cues in the environment and elements in the mental model.

Although there is considerable evidence that decision makers use pattern matching to recognize perceived information as a particular exemplar of a known class of situations (e.g., Hinsley, Hayes, & Simon, 1977; Klein, 1989; Zsambok & Klein, 1997), the nature of situation classification varies with domain expertise as found in formal domains such as physics (e.g., Chi, Feltovich, & Glaser, 1981). When categorizing physics problems, novices often rely upon surface features of problems, whereas experts use underlying features of problems to represent problems. In the present domain of aviation, control and performance elements that respectively reflect causes and effects of flight situation changes may correspond to the surface and deep features of problems for pilots to represent their flight situations. Operations on control elements can thus be cognitively different from those on performance elements. Our data suggest that novice pilots tend to rely on representations of performance flight elements whereas expert pilots tend to rely on representations of control flight elements. This evidence supports for differences between novices and experts in the use of situational information for pattern matching.

In addition to the implication for SA theory, the present research has an implication for SA measurement. Our findings address an ongoing discussion among aviation researchers regarding the validity of the Situation Awareness Global Assessment Technique (SAGAT) as a measure of SA (e.g., Durso & Gronlund, 1999; Endsley, 1995c; Endsley & Garland, 2000). Using SAGAT, a system simulation is frozen at randomly selected times and operators are queried as to their perceptions of the situation at that time. The system displays are blanked and the simulation is suspended while subjects answer questions about their current perceptions of the situation. This method involves the subject's ability to recall information about the situation from memory and a concern has been raised that this method relies too heavily on LTM in particular. In fact, answering a set of questions requires subjects to make SA information available for quite some time after a freeze. Based on the present data, it is likely that experts have LTM stores (such as mental models and schemata) that serve to organize information and have an effect on its availability for a measure such as SAGAT. This supports the validity of SAGAT as a SA measure, particularly for expert operators who have much greater ability to access LTM than novice operators.

In sum, the componential analysis of memory processes was profitable to understand the memory components to form SA. Although most of the studies on human sensibility have focused on affective and physiological aspects of user-system interactions, the present research focused on higher-order cognitive aspects of user-system interactions (i.e., pilot-cockpit interactions). In order to advance our understanding of how sensibly users interact with complex systems such as aircraft cockpit displays, it is necessary to analyze cognitive processes underlying user sensibility. However, an analysis of componential parts that are central to achieving SA would have limitations to understand the configural whole of SA. SA is configural, requiring the integration of multiple cognitive and affective processes. In order to further our understanding of SA, research on dynamics between cognitive and affective processes in creating high levels of SA sensitivity would be of more interest.

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