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Metacognitive Situation Awareness in Aviation

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This exploratory study was aimed at gaining a better understanding of metacognitive situation awareness. Seven subject matter experts, two each for commercial aviation and aviation maintenance and three for air traffic control, were asked to define 'situation awareness' as it relates to their job and identify the knowledge, skills, and strategies enabling them to effectively monitor, evaluate, and regulate their situation awareness as they perform their job. Findings from this line of research can guide the design, development, and evaluation of approaches for enhancing and assessing metacognitive situation awareness.

Metacognitive situation awareness refers to the operator's ability to monitor, evaluate, and regulate their situation awareness. Metacognitive monitoring of one's situation awareness has been shown to influence performance in both safety-critical roles, such as air traffic control (McNally et al., 2017; Sethumadhavan, 2011) and command and control (Rousseau et al., 2009), as well as more mundane tasks such as driving (Soliman & Mathna, 2009). In essence, metacognitive situation awareness is a higher order cognitive skill bridging the cognitive processes of situation awareness and metacognition, as described next.

Endsley (1995, p. 36) formally defined situation awareness (SA) as "…the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future." Simply stated, SA involves being aware of what is happening around you to understand how information, events, and your own actions will impact your goals and objectives, both now and in the near future. Although alone it cannot guarantee successful decision making, SA does support the necessary input processes (e.g., cue recognition, situation assessment, prediction) upon which good decisions are based. Numerous studies have highlighted the vital role of SA to ensure successful performance in complex domains (e.g., Artman, 2000; Endsley, 1993; Furniss & Blandford, 2006; Sharma et al., 2019; Skrypchuk et al., 2020).

Metacognition has been defined as the awareness of one's own cognitive processes and the ability to understand, control, and manipulate these processes (Davidson et al., 1994, Osman & Hannafin, 1992). Metacognition, therefore, involves two distinct dimensions: knowledge of one's cognitions and regulation of these cognitions (Schraw, 1998). Knowledge of cognition refers to one's awareness and understanding of one's own thoughts and cognitive processes. Regulation of cognition refers to the behaviors one enacts to control and manipulate these processes, such as seeking new information and self-testing one's knowledge. Metacognition has a long established history of research demonstrating its importance for numerous cognitive outcomes. Metacognition plays an essential role in communication and comprehension (both oral and written; see Flavell, 1979), problem solving (e.g., Davidson et al., 1994; Davidson & Sternberg, 1998; Mayer, 1998), memory (e.g., Bjork, 1994; Brown, 1978), and self-regulated learning (e.g., Gourgey, 1998; Hofer et al., 1998; Winne & Hadwin, 1998; Winne & Stockley, 1998). Metacognition has also been shown to be critical to the development of expertise (Glaser, 1989; MacIntyre et al., 2014; Osman & Hannafin, 1992; Smith et al., 1997; Sternberg, 1998).

Method

The aviation domain involves completion of dynamic, highly technology-dependent operations and affords different aviation settings for exploring metacognitive situation awareness. This initial study focused on three settings: commercial aviation, air traffic control, and aviation maintenance. Seven subject matter experts (SMEs), two each for commercial aviation and aviation maintenance and three for air traffic control, were individually asked to respond to the following two questions: (1) Define 'situation awareness' as it relates to your job, and (2) What knowledge, skills, and strategies enable you to monitor, evaluate, and regulate your situation awareness as you perform your job? Below are brief summaries of each SME's background, organized by domain.

Commercial Aviation (CA)

CA-SME-1 holds FAA ATP, CFI, CFII, MEI and Advanced Ground Instructor licenses and ratings and currently has just under 5,000 hours of flight time logged over a period of 40 years. CA-SME-1 has been employed as a regional airline captain for the past three years. Prior to this, CA-SME-1 worked as a flight simulator instructor for one and half years. CA-SME-2 has experience in multiple aircraft as Captain (A-320 / B-737-200 / 300 / 500 / 700 /800 / 900) and as First Officer (B-777 / B-747 / B-767 / 757 / B-737). CA-SME-2 is currently employed as a Captain on the B-737 and as a Line Check Airman and has been working in this occupation for 30 years. CA-SME-2's previous occupation was as a U. S. Air Force pilot (T-38 Instructor, F16 Fighter Pilot; HC-130 Combat Rescue Operations), for 13 years active duty and then 8 years in the U. S. Air Force Guard/Reserve.

Air Traffic Control (ATC)

ATC-SME-1 received training in the U. S. Air Force and then transitioned to the civil air traffic domain, spending eight years in the FAA. ATC-SME-1's experience includes controlling in the tower, approach control, and area control. Currently, ATC-SME-1 works as an ATC Instructor in both tower and radar and has been in this occupation for 29 years. ATC-SME-2 began in air traffic control in the U. S. Air Force and then worked civilian ATC before transitioning back to the military. ATC-SME-2 is currently employed as an Air Traffic Supervisor and has been in this occupation for 21 years. ATC-SME-3 controlled aircraft both in a tower and radar environment at six different facilities, ranging from a VFR tower to a major international airport, then retired from the FAA and started teaching air traffic control. ATC-SME-3 is currently employed as an Associate Professor in Air Traffic Management and has been in this position for 14 years. Prior to this, ATC-SME-3 work for 27 years as an Air Traffic Controller and Supervisor.

Aviation Maintenance (AM)

AM-SME-1 is a U. S. Army trained CH47 rotary wing mechanic, A&P certified. AM-SME-1 worked in the Army for seven years and then transitioned to industry, working in aviation safety, hazmat, tool control, and maintenance. AM-SME-1 currently is employed in quality control as a Technical Inspector and has worked in the aviation industry for 19 years. Prior to this, AM-SME-1 worked in automotive maintenance for five years. AM-SME-2 is employed as a technician, supervisor and Chief Inspector working in a 14 CFR Part 145 Repair

Station for aircraft operated by general aviation operators, 135 operators and air carriers. AM-SME-2 has been in this occupation for 43 years. Prior to this, AM-SME-2 worked as a motorcycle technician for seven years.

Results and Discussion

Results are organized by the three aviation settings: commercial aviation, air traffic control, and aviation maintenance. Common themes across settings are also discussed.

Commercial Aviation

CA-SME-1 defined SA as one's innate, learned, and practiced ability to evaluate the operating environment, while considering various environmental inputs, to identify errors and threats as they arise to ensure appropriate actions can be taken to maintain safe operations. CA-SME-2 described SA as the ability to see and comprehend the 'big picture,' while simultaneously conducting other relevant tasks. The CA-SMEs collectively agreed the knowledge, skills, and abilities required for commercial pilots to effectively monitor their SA are drawn from both crew resource management and recurrent training. According to CA-SME-1, commercial airline pilots use the 'Prepare, Repair, Recover' strategy drawn from crew resource management model of situation awareness to monitor the SA of the flight team. To achieve this, briefs and debriefs are used to assist in the SA monitoring process. CA-SME-2 also highlighted the importance of recurrent training and the use of checklists as additional tools and strategies commercial airline pilots use to monitor their SA. According to CA-SMEs, the knowledge, skills, and strategies enabling commercial airline pilots to evaluate their SA are drawn from training. CA-SME-1 identified the crew resource management model as an effective tool to identify errors and threats at an early stage to ensure a quick return to safe operating conditions. Additionally, CA-SME-1 emphasized the importance of recognizing the following identifiable barriers to good SA: poor workload management, complacency, failure to share information, distractions, fixation, ineffective communication, slang and acronyms, stress and fatigue, and poor briefings. The CA-SMEs agreed effective regulation of one's SA is achieved through the knowledge, skills, and strategies drawn from the experience of training and recurrent training. Additionally, CA-SME-1 emphasized the importance of developing a deeper understanding of one's own cognitive biases. CA-SME-1 described the '3D' strategy as a useful SA regulation tool: pay attention to every *detail*, practice *diligence* consistently, and maintain *discipline* to resist the temptation to deviate in real time.

Air Traffic Control

The ATC-SMEs collectively defined SA as the process of acquiring and maintaining an accurate mental picture of the managed airspace in terms of ongoing traffic, while anticipating the potential for unexpected changes. Per the ATC-SMEs, the knowledge, skills, and abilities required for an air traffic controller to effectively monitor their SA include good listening skills, scanning techniques, and background knowledge drawn from the experience of working in the field. Both ATC-SME-1 and ATC-SME-2 highlighted the importance of using the past experience of having managed various types of airspace traffic as the foundation for the knowledge, skills, and abilities required to assist in the monitoring process. The ATC-SMEs collectively agreed prior experience and previous knowledge of airspace traffic flow are required to evaluate one's SA while controlling the airspace. Drawing from the predictability of experience and a keen understanding of how pilots behave and handle their aircraft provides air traffic controllers with the premise to evaluate their own SA. The ATC-SMEs identified the importance and utility of having a foundational understanding of federal rules and regulations encompassing air traffic control operations aids in the process of regulating one's SA as an air traffic controller. According to the ATC-SMEs, additional strategies could be implemented to regulate one's SA, such as minimizing extraneous discussions with fellow controllers and tuning in to other frequencies to stay up-to-date on what is happening within their managed airspace.

Aviation Maintenance

AM-SME-1 defined SA as paying attention to the paperwork, the environment in which you are performing maintenance, the items being inspected, and measurement and mitigation of any risks associated with any of the above. In terms of knowledge, skills, and strategies to support their M-SA, AM-SME-1 highlighted the importance of experience, teamwork, constant vigilance, and carefully assessing and continually reassessing the situation, especially with regard to risk assessment. AM-SME-2 defined SA as a comprehensive analysis of all of the aspects of aircraft maintenance, operations, crew operations and how they are interdependent. AM-SME-2 also highlighted the importance of risk assessment, relying on historical information, trend analysis, accident analysis and predictive techniques. The goal is to eliminate repetitive operation discrepancies, reduce Time Between Failures (TBF), analyze dispatch rate success, and meet industry standards for operational safety and efficiency.

Common Themes across Settings

In defining SA, the SMEs all highlighted the ability to formulate and maintain an accurate picture, with consideration for the interdependence of multiple elements in the operational environment as well as other relevant tasks. When asked to identify the knowledge, skills, and abilities required to effectively monitor, evaluate, and regulate their SA, the SMEs all emphasized the importance of risk management, including diligence and measurement and mitigation of any risks. Other common themes across the three operational settings included training, background knowledge and experience, communication skills, teamwork, constant vigilance, and avoiding distractions. Elements of crew resource management were explicitly identified by the CA-SMEs and implied in the responses from the ATC-SMEs and AM-SMEs.

Study Limitations and Implications for Future Research

Findings in this exploratory study are promising but limited by the small number of SMEs. Also, the depth of the responses were varied, with some SMEs providing greater details and others less details. To address these limitations, future research is warranted with a larger number of SMEs and in-depth questions designed to elicit more detailed responses. For instance, the SMEs could be asked to provide real-world examples demonstrating the application of the knowledge, skills, and strategies they identified. Future research could also solicit input from SMEs in other aviation settings such as unmanned systems, ground and ramp operations, and airport operations. With a richer understanding of the knowledge, skills, and strategies underlying metacognitive situation awareness, a conceptual framework can be proposed to inform a quantifiable operationalization of this construct. In turn, this quantifiable operationalization would enable translating the three components of metacognitive situation awareness (monitor, evaluate, and regulate) into observable behaviors. To illustrate, knowledge important for metacognitive situation awareness could be demonstrated by answering knowledge questions. Essential skills could be demonstrated by executing tasks for which the skill is needed. Strategies supporting effective metacognitive situation awareness could be demonstrated in realistic simulated scenarios and evaluated by trained observers.

Conclusion

Findings from this line of research can guide the design, development, and evaluation of approaches for enhancing and assessing metacognitive situation awareness. Insights gained from a broader range of SMEs can inform the development of training programs targeting key knowledge, skills, and strategies underlying metacognitive situation awareness. A quantifiable operationalization of metacognitive situation awareness can be used to develop valid and reliable measures to evaluate the effectiveness of such programs as well as the utility of decision aids aimed at supporting operator metacognitive situation awareness.

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