Situation awareness (SA) is defined as one’s perception of the elements of the environment, the comprehension of their meaning, and the projection of their status in the near future. The concept of SA is well known in the aviation industry, which is characterized by complexity and dynamism. The discipline of anesthesia shares these same environmental characteristics, yet the study of SA in this setting is in its infancy. Guided by Endsley’s theory of SA, the purpose of this study was to provide educators with a best-evidence predictor model of SA in student registered nurse anesthetists (SRNAs).

Seventy-one SRNAs were randomly selected from 3 US universities. A nonexperimental, correlational design and multiple regression analysis were used to measure the relationship between memory, cognition, and automaticity and SA. Findings from this study reveal cognition as the best predictor of SA in graduate SRNAs, with the addition of memory and automaticity contributing no additional predictive value to the model. The results of this study have the potential to make a positive impact on the admission, education, and training of SRNAs. This study contributes evidence for further research examining the use of high-fidelity simulation in promoting SA in SRNAs.

Keywords: Awareness, education, simulation, situation awareness, training.

On January 15, 2009, Captain Chesley “Sully” Sullenberger gained international recognition for the flawless landing of an Airbus A320 on the Hudson River in New York City following a dual-engine power failure. Captain Sullenberger reported a keen awareness from the moment the aircraft lost power that he was amid a critical situation given the low-speed and low-altitude conditions while flying over one of the most densely populated areas in the country. Yet, when asked in an interview shortly after the incident what kept him up at night, he stated, “Were we aware of everything we could have been aware of?”

Situation awareness (SA) is a construct dating to the early 20th century. In flight, military aviators in World War I needed to possess a continuous and keen awareness of self in relation to enemy aircraft while maintaining control of a dynamic environment. Situation awareness is demonstrated as one’s ability to know what is going on in his or her surroundings at any given moment in time and is acknowledged as an essential skill in the successful management of complex environments, inclusive of anesthesia practice, in which decisions must be made rapidly and under times of distress. Situation awareness has been confused with vigilance, a term more common to nurse anesthetists. Although closely related, vigilance is the ability to maintain attention over prolonged periods, whereas SA is a 3-level construct defined as one’s “perception of the elements of the environment, the comprehension of their meaning, and the projection of their status in the near future.” Despite recent quality improvements in the practice of anesthesia, SA remains a key, but not completely understood, component of delivering safe and effective anesthesia care.

Problem and Importance of Study. While morbidity and mortality related to anesthesia have declined dramatically over the past 2 decades, when complications do occur, they can be catastrophic, resulting in brain damage, paralysis, nerve injury, or even death. Because of the infrequent occurrence of anesthesia-related crises, nurse anesthesia educational programs are challenged to find effective methods that best prepare learners to manage these nonroutine critical events. Clinical rotations during training of student registered nurse anesthetists (SRNAs) do not guarantee exposure to the chaos of an ensuing emergency. Furthermore, most nurse anesthesia programs do not incorporate formalized didactic training targeted at anesthesia crisis management, of which the acquisition and enhancement of SA is a key component. Instead, crisis management skills are assumed to develop through didactic coursework and during clinical rotations in the operating room. Nevertheless, Certified Registered Nurse Anesthetists (CRNAs) must be prepared to effectively manage crises that rarely occur in practice by possessing adequate SA to bring all resources to bear.

Theoretical Framework. The underpinnings of this study lie in Mica Endsley’s theory of SA. In the early 1980s, Endsley and her coworker began to study SA as a human factor that may contribute to performance...
in pilots. According to Endsley, SA is a construct that describes the ability of operators of complex systems to be aware of salient elements in their environment. In their seminal work with aviators, Endsley and Garland\(^4\) identified the constructs of memory, cognition, and automaticity as individual attributes that may determine one’s ability to develop SA.

The theory of SA proposes that anesthesia providers as operators of, and workers within, complex systems have the ability to perceive what is going on in the environment (eg, 1,000 mL of blood noted in the suction canister during surgery), understand what this means (the patient has less blood volume and hemoglobin circulating through his cardiovascular system), and project into the future the implications of such an event (there is a decreased capacity to carry oxygen to vital organs, which could lead to multisystem organ failure and death). The time it takes for the anesthesia provider to develop SA is crucial because human physiology, in the face of an insult such as profound blood loss, will not pause for the anesthetist’s effective resolution of the crisis. The quality of a patient’s outcome may largely depend on the anesthesiologist’s level of SA. Research focused on the enhancement of nontechnical skills, such as SA, continues to be an area of interest in the specialty of anesthesia\(^2\)-\(^11\).

The purpose of this study is to provide nurse anesthesia educators with a best-evidence predictor model of SA in the SRNA population employing the Endsley model. This work examines individual attributes that contribute to the development of SA by exploring the relationships between memory, cognition, and automaticity and SA in SRNAs. This study has quality implications for anesthesia providers, educators, and the millions of patients who put their trust in the nation’s healthcare system.

**Materials and Methods**

- **Research Design.** After institutional review board (IRB) approval, an exploratory, nonexperimental, correlational design was used to examine the influence of memory, cognition, and automaticity on SA in SRNAs. The population included SRNAs enrolled in accredited nurse anesthesia programs from a convenience sample of 3 large US universities: Virginia Commonwealth University, Richmond, Virginia; Louisiana State University, New Orleans, Louisiana; and Samford University, Birmingham, Alabama. A power analysis, using \( \alpha = .05 \) and \( \beta = .20 \), indicated a minimum sample size of 57 to achieve type II power of at least 0.8.\(^12\)-\(^14\)

The 3 predictor variables chosen for this study were based on Endsley’s theory of SA and a thorough review of the SA, cognitive psychology, and anesthesiology literature. The predictor variables included memory, cognition, and automaticity. Although several variables, according to Endsley and Garland,\(^4\) are hypothesized to predict SA, memory, cognition, and automaticity were examined in this study largely because of their potential to be addressed by curricular strategies in nurse anesthesia education. The inclusion of age and gender as covariates removed age and gender bias that would have otherwise eliminated the ability to generalize the results of the study and helped to establish a deeper understanding of what contributes to SA in SRNAs. The criterion variable was SA.

- **Measure of Working Memory.** Both long-term memory and working memory are involved in the development of SA.\(^4\) Long-term memory plays a role in mental model development, which directs one’s attention appropriately given the task at hand. Working memory plays a substantial role in combining and interpreting information obtained from the environment and has a fixed and limited capacity, which varies from person to person.\(^15\) Working memory is essential to achieving high levels of SA in challenging environments.\(^4\) Digit Span, a subtest of the revised Wechsler Adult Intelligence Scale (WAIS-III), is a valid and reliable measure of working memory and was used as the measure of memory in this study.\(^16\)-\(^18\)

- **Measure of Cognition.** Endsley and Garland\(^4\) suggest that cognitive processes, such as pattern matching, conscious analysis, story building, and mental simulation, all may be used by operators at various times to develop SA. Raven’s Standard Progressive Matrices (SPM)\(^19\) was designed to assess these abilities as well as one’s ability to reason by analogy, think clearly, and make sense of complex situations independent of language and education level. Raven’s SPM is a valid and reliable measure of Spearman’s g, a quality in the human brain that generates cognitive and intelligent behavior, in subjects aged 6 years to adult.\(^19\)-\(^20\) Raven’s SPM was employed to measure cognition in this study.

- **Measure of Automaticity.** Automaticity refers to the ability to perform a task while putting little thought into it and has been identified as a defining characteristic of an expert.\(^21\) According to Endsley and Garland,\(^4\) as work becomes more automatic, the demands burdening one’s ability to gain SA are diminished. Automaticity is achieved through learning, repetition, and practice and is gained through experience.

As a prerequisite to entry into all nurse anesthesia programs in the United States, SRNAs are required to have at least 1 year of acute care nursing experience in which one develops skills as an independent and capable decision maker. Often these settings are intensive care units (ICUs). The complex and dynamic nature of nursing in the ICU mirrors the nature of nurse anesthesia practice in that both patient care environments require a keen and continuous awareness of a multitude of rapidly changing stimuli. Based on the association between automaticity and experience, the length of time (in months) working in the ICU as a professional nurse before formal nurse anesthesia training was used as a measure of automaticity in this study.
Measures of Demography. Age and gender were used in the statistical analysis as blocking variables to eliminate their impact on the generalizability of the results. Age was reported in years, rounded to the closest year. Gender served as a dichotomous variable: male or female.

Measure of Situation Awareness. Situation awareness has been measured in disciplines that require human beings to manage complexity, such as air traffic control systems, self-defense arenas, military operations, aviation, simulated medical environments, and command and control environments.

Situation awareness was measured in this study by the Wondrous Original Method for Battle Airmanship Testing in Complex Systems (WOMBAT-CS). The WOMBAT-CS Situation Awareness and Stress Tolerance Test is a modern computer-based measure of SA that has been validated and shown to be reliable in pilots. The WOMBAT-CS is designed to measure an operator’s ability to scan a generic and culture-independent complex environment for multiple sources of information, prioritize requisite tasks, and entertain viable alternative decisions and actions.

During WOMBAT-CS testing, the operator is challenged to keep a crossbar in a moving circle target in order to engage an autopilot mechanism. Once the autopilot mechanism is engaged, the operator is asked to do a series of cognitively challenging bonus activities, all while keeping a watchful eye on the autopilot. As the autopilot becomes spontaneously disengaged, the operator is expected to be aware of this critical change and leave the bonus activities to reengage the autopilot; the more optimal the overall performance, the more maximized the overall total score. The WOMBAT-CS is an electronically controlled device that gathers this performance data based on the operator’s responses and input via 2 joysticks connected to a laptop computer by way of a standard parallel connection. The program’s software collects and reports user scores. The WOMBAT-CS is a self-administered, 90-minute evaluation, which provides a quantitative score of SA on its completion.

Research Hypotheses. It was hypothesized that higher scores on measures of memory, cognition, and automaticity would be associated with higher SA scores as measured by the WOMBAT-CS in this population. The research hypotheses (H) were as follows:

H1: There will be a direct positive linear relationship between memory and SA.
H2: There will be a direct positive linear relationship between cognition and SA.
H3: There will be a direct positive linear relationship between automaticity and SA.
H4: A combination of memory, cognition, and automaticity will produce a more predictive model of SA than that produced by memory, cognition, or automaticity alone.

Results
Data were collected from 111 subjects across 3 US universities. A Missing Values Analysis (MVA) using statistical analysis software (SPSS version 17.0, SPSS, Chicago, Illinois) identified the extent to which 36 missing scores on the WOMBAT-CS affected the analysis. Little’s MCAR (missing completely at random) test revealed that the missing values were not missing completely at random ($\chi^2 = 26.26, df = 8, P = .001$). Additionally, 4 cases with multivariate outliers were discovered. As a result, all cases missing WOMBAT-CS scores as well as those with multivariate outliers were eliminated from the analysis, leaving 71 valid cases as the final sample for analysis.

Descriptive Statistics. Descriptive statistics on each
observed variable are presented in the Table. They include number of cases, mean ± standard deviation (SD), variance, and minimum and maximum (range) values.

• Gender and Age. Gender represents the single categorical variable. Women comprised 69% (n = 49) of the sample and men comprised 31% (n = 22) of the sample. This pattern of distribution is not congruent with the distribution of men and women in the population of CRNAs in the United States. Results of a demographic survey of CRNAs by the American Association of Nurse Anesthetists revealed a distribution of 50% men and 50% women.26

To address this discrepancy, a 1-way homogeneity of variance test for gender against each predictor and the criterion SA was performed to determine if significant variance between women and men on each variable existed.14 Levene’s statistic revealed no significant violation of homogeneity of variance for any of the study variables, indicating equal variance for men and women on all of the observed variables.

Age served as a covariate in the analysis to explore its relationship with SA in the population of SRNAs. The sample mean was 30.9 years, with an SD of 4.61. The sample ranged from 25 to 46 years at the time of testing. Skew was corrected with a transformation of age to the natural log of age and labeled AGELOG. Age was related to its transform (AGELOG), with r = 0.996.

• Memory. Memory was measured by scores on Digit Span.27 The mean value for memory was 9.7 digits, with an SD of 2.45. Scores ranged from a low of 5 to a high of 19 digits. Current literature reflects a normal memory capacity to range from 7 to 10 items.28 Analysis revealed that 74% of cases (n = 53) had scores between 8 and 12 digits. Because the range suggested univariate outliers but the data were normally distributed, generalizability was possible but limited to scores in the middle of the distribution. Therefore, a z-transformation was performed on memory and labeled MEMRZ. Memory was related to its transform (MEMRZ), with r = 1.0.

• Cognition. Cognition was measured by Raven’s SPM examination. The mean score for cognition was 54.5, with an SD of 3.39. Scores ranged from a low of 44 to a maximum of 60.

• Automaticity. Automaticity was measured by the length of time (in months) that subjects worked as registered nurses in the ICU before admission into the nurse anesthesia program. The mean value for automaticity was 51.9 months, with an SD of 36.63. Scores ranged from a low of 12 to a high of 192 months. A large number of subjects had relatively little ICU experience, whereas a few appeared as outliers with a large number of months of experience. Given the pattern of the data, a z-transformation on automaticity was performed to account for the distribution of data expected in a population of SRNAs and was labeled AUTOZ. Automaticity was related to its transform (AUTOZ), with r = 1.0.

• Situation Awareness. Situation awareness was measured by quantitative scores on the WOMBAT-CS computer-based examination of SA. The mean value for SA was 150.2, with an SD of 73.87. Scores ranged from 11.7 to 333.8.

• Findings for Hypotheses. H1: There will be a direct positive linear relationship between memory and SA. Hypothesis 1 was tested by computing a Pearson product moment correlation (r) on the variables memory and SA. Correlation matrix output from SPSS 17.0 revealed an r value of 0.204 (P = .088), which does not provide adequate evidence to support hypothesis 1 (H1). The coefficient of determination (r²) between memory and SA was computed as 0.042, indicating that 4.2% of the variance in SA is explained by the variance in memory.

H2: There will be a direct positive linear relationship between cognition and SA. Hypothesis 2 was tested by computing a Pearson product moment correlation (r) on the variables cognition and SA. Correlation matrix output revealed a moderate association between cognition and SA, with an r value of 0.442 (P = .000), which is statistically significant at the .01 level (2-tailed) and provides sufficient evidence to support hypothesis 2 (H2). The coefficient of determination (r²) between cognition and SA was calculated as 0.195, indicating that approximately 20% of the variance in SA is explained by the variance in cognition.

H3: There will be a direct positive linear relationship between automaticity and SA. Hypothesis 3 was tested by computing a Pearson product moment correlation (r) on the variables automaticity and SA. Correlation matrix output from SPSS 17.0 revealed an r value of −0.128 (P = .287), which does not provide adequate evidence to support hypothesis 3 (H3). The coefficient of determination (r²) between automaticity and SA was computed as 0.016, indicating that 1.6% of the variance in SA is explained by the variance in automaticity.

H4: A combination of memory, cognition, and automaticity will produce a more predictive model of SA in the SRNA population than that produced by memory, cognition, or automaticity alone. Statistical (stepwise) regression was employed to test hypothesis 4 (H4). In the stepwise analysis, both covariates (gender and age) and all predictors (memory, cognition, and automaticity) were first entered against the criterion (SA). A single variable, cognition, was determined to be significant (F = 16.87, df = 1/69, P < .001) to enter into the final regression analysis. Cognition and SA had both a univariate and multivariate r value of 0.442, explaining nearly 20% of the variance in SA. Age and memory were half as important as cognition and of approximately equal importance when compared with each other, with partial correlations of −0.21 and 0.17, respectively.

Based on the stepwise regression, there was insufficient evidence to support hypothesis 4 (H4). Thus,
this study finds that cognition best predicts SA in the population of SRNAs, with the addition of memory and automaticity contributing no additional predictive value to the model.

Discussion

• Anesthetic Implications. The results of this study have practical implications for nurse anesthesia educators, anesthesia providers, and, ultimately, the countless patients for whom they provide care. Program directors and faculty of nurse anesthesia programs are challenged to teach students the essential theoretical and technical knowledge and skills necessary to be effective in the operating room environment. Effective management of life-threatening crises arising in the operating room is among the most challenging essentials to be taught and instilled in learners. Knowledge of what may or may not contribute to SA in SRNAs has the potential to assist educators in best utilizing scarce human and capital resources efficiently and effectively to reach these programmatic outcomes.

Problem solving is regarded by many educational and cognitive psychologists as fundamental to learning.39-41 Adequate SA may contribute to one’s ability to solve problems effectively.4,29 A learner is thought to analyze a problem by assigning it to some preexisting mental model formed from previous experience. Cognitive processes allow the learner to reconcile the current problem with the preexisting mental model in order to come to a solution. In the transition from novice to expert, learners of anesthesia may not yet possess a comprehensive set of reconciliation skills or mental models necessary for effective problem solving during a nonroutine event in the operating room.

The use of simulated operating rooms in nurse anesthesia training programs shows promise for providing opportunities for SRNAs to experience nonroutine and critical events. Through this exposure, students can potentially begin to create the mental models essential for effective problem solving and accurate decision making under stressful conditions.29 Once mental models of these rare events are established, nurse anesthesia faculty can incorporate cognitive exercises such as lateral thinking, mental manipulation of relationships, and reconciliation of information into hands-on training in the simulated operating room environment to promote SA.

Additionally, nurse anesthesia educators may consider the feasibility of instructional methods that are grounded in anesthesia-specific cognitive task analyses. Cognitive task analysis has been used to train operators of complex systems to develop the cognitive and decision-making skills necessary to manage the chaos of complex environments.32,33 The goal of cognitive task analyses is to capture the work environment and cognitive processes requisite to achieving an operator’s goal.34

For example, specific critical incidents in anesthesia must first be identified (difficult airway management, pneumothorax, malignant hyperthermia, etc). Then instructors can choose to develop evidence-based hands-on experiences in the simulated operating room that would provide real-time critical decision-making opportunities for SRNAs while incorporating unpredictable and unfamiliar external events. Student registered nurse anesthetists can be challenged to think critically, reevaluate priorities as the crisis unfolds, understand the consequences of tentative decisions, and process indirect and ambiguous cues. Such hands-on experiences in high-fidelity simulated operating rooms may offer learners an opportunity to assimilate cognitive processes with desired performance behaviors and establish mental models that may serve them in their practice as CRNAs.

Another potential practical application of the current research findings relates to admissions processes of nurse anesthesia programs. Currently, the criteria for admission into a nurse anesthesia program in the United States are established by each individual program. However, according to the Council on Accreditation of Nurse Anesthesia Educational Programs (COA), admissions criteria must include at least a bachelor of science in nursing or another appropriate baccalaureate degree, an active license as a registered nurse, and a minimum of 1 year of acute care nursing experience. The reason for the long-standing accreditation standard of 1 year of acute care experience is not well described or documented but is embraced by nurse anesthesia faculty as a measure of some desirable level of critical thinking and technical aptitude necessary for successful completion of the program.

Despite the requirement for acute care experience, some students still fall short of the necessary skills to manage the complexity and uncertainty characteristic of the operating room environment. The findings of this study support this notion in that no significant relationship was found between automaticity, measured by length of time working in the ICU, and SA. Perhaps, the prerequisite 1-year acute care nursing experience is not as predictive of successful performance in the program as once thought to be, and other more defined and evidence-based admissions criteria could be established to prepare applicants as independent decision makers capable of using and interpreting advanced monitoring and therapeutic modalities.

For example, in the current study, subjects with higher cognitive abilities demonstrated higher levels of SA. The Raven’s SPM, an economical, easy-to-administer, paper-and-pencil test of cognition, may have utility in the admissions process as a more reliable predictor, when compared with acute care experience, of an applicant’s ability to manage complexity, make critical decisions, and solve unfamiliar problems. Further research evaluat-
ing the efficacy of this tool in the admissions process is recommended.

• Limitations to the Study. The WOMBAT-CS is a quantitative and generic measure of SA. It has been demonstrated to be a valid measure of SA in the aviation industry.22 Face validity of the WOMBAT-CS in the population of SRNAs was established in this study after a thorough comparison of operator characteristics and complex working environments between anesthesia and aviation was made based on the literature. However, individual differences between pilots and SRNAs may exist. Future studies empirically validating the WOMBAT-CS in the nurse anesthesia domain are warranted. A study similar to O’Hare’s22 could be conducted comparing nonanesthetists, novice CRNAs, and expert CRNAs. If study results were to reveal the highest scores on WOMBAT-CS for expert CRNAs and the lowest scores on WOMBAT-CS for nonanesthetists, predictive validity of the WOMBAT-CS in a population of nurse anesthetists could be considered.

Endsley and Garland4 suggest that any measure of automaticity should aim to capture highly routine action-sequence sequences developed with experience and that it should be domain specific. Because all SRNAs are required to have acute care nursing experience and the environment in the ICU has been likened to the environment in the operating room, length of time working as a registered nurse in the ICU was chosen as a measure of automaticity. With no evidence of a relationship between automaticity and SA in this study, more empirical attention directed at defining and developing more domain-specific measures of automaticity will serve future work in this area and contribute to a better understanding of Endsley’s theory of SA.

The issue of attrition is of concern given that 36 subjects had no scores on the measure of SA. It is important to consider that subjects opting to forgo the WOMBAT-CS assessment may differ somehow from subjects who completed the assessment. Also, a convenience sample of nurse anesthesia programs was chosen for this study. This convenience sample was taken from 3 nurse anesthesia programs in the southeastern United States, and although the study findings may have regional generalizability, the sample of programs may not be representative of other nurse anesthesia programs in the United States.

Conclusion

Human error, often resulting from a loss of SA, continues to adversely affect the US healthcare system. Anesthesia is a healthcare specialty known to be susceptible to error and, occasionally, poor patient outcomes. A critical analysis of the most vulnerable processes involved in the delivery of anesthesia should be further considered to optimize human performance and maximize positive patient outcomes. Endsley’s theory of SA has potential to serve as an effective framework for further investigation of the influence of SA in preventing and managing crises in the anesthesia domain.

Exploration of the utility of high-fidelity simulated operating rooms in developing and enhancing SA and other essential nontechnical skills such as decision making and problem solving is warranted in the education of SRNAs. This hands-on applied teaching method gives educators opportunities to enhance students’ critical thinking and other domain-specific cognitive skills. Through simulation, instructors can explore and study elements of successful crisis management, including SA, in an environment that poses no risk to patients. Patient safety is one of the most important markers of quality in healthcare. A critical precursor to safety is properly trained healthcare providers who are not only technically competent but also critical thinkers and adept crisis managers. Because crises in anesthesia are rare events, nurse anesthesia educators are charged with producing graduates able to meet the complex and rapidly changing demands characteristic of the specialty. Future educational programs of research directed at gaining a better understanding of SA and its role in the provision of safe anesthesia have the potential to make substantial contributions to nurse anesthesia training and patient safety.

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ACKNOWLEDGMENT
The authors would like to thank the AANA Foundation for its support of this research, and Aero Innovation Inc for making the WOMBAT-CS SA measurement tool available for this study.