Situation Awareness in Anesthesia

Concept and Research

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ABSTRACT

Accurate situation awareness (SA) of medical staff is integral for providing optimal performance during the treatment of patients. An understanding of SA and how it affects treatment of patients is therefore crucial for patient safety and an essential element for research on human factors in anesthesia. This review describes the concept of SA in the anesthesia environment, including the interaction with associated medical teams. Different approaches for its assessment in the work environment of anesthesia are provided. Factors contributing to expertise in SA are described and approaches for the training of SA in anesthesia are discussed, as are types of errors that occur during the development of SA. Finally, the authors briefly present strategies to improve SA during daily anesthesia practice through altered designs of monitor displays.

SITUATION awareness (SA) is defined as "the *perception* of elements of the environment within a volume of time and space, the *comprehension* of their meaning and the *projection* of their status in the near future."[1] It describes the ability of an individual to maintain an adequate internal representation of the status of the environment in complex and dynamic domains where time constants are short and conditions may change within seconds and minutes. The concept was first used in the field of military and commercial aviation and described in detail for the first time in the late 1980s by Endsley.[1] According to the definition, SA is subdivided into three hierarchical levels: perception (SA level I), comprehension (SA level II), and projection (SA level III).[2]

In 1995, the concept of SA was introduced into the field of anesthesia by Gaba *et al.*[3] Later, SA was classified as an important nontechnical skill[4] and was embedded in the Anaesthetists' Non-Technical Skills (ANTS) taxonomy and behavior rating tool. This framework was designed especially for anesthetists and identified four main nontechnical skills: situation awareness, decision-making, teamwork, and task management.[5]

In this review, the concept of SA is presented, and its importance for accurate decision-making and performance is illustrated. Insights into different approaches for the assessment of SA are provided and skills that are related to high levels of SA are described. Starting from a cognitive theoretical background, we identify types of error that may occur during the development of SA. Furthermore, implemented SA training strategies from other domains are described and discussed with respect to their applicability in anesthesia. Finally, we briefly present strategies to improve the design of patient monitors with respect to SA during daily anesthesia practice.

What Is SA?

The term *SA* has been used with respect to individuals, teams,[1] and systems.[6] To illustrate these different approaches, a critical incident is presented:

Case Example

A 68-yr-old man presented with an acute abdominal crisis and clinical signs of sepsis. General anesthesia was induced by a fourth-year anesthesia resident for exploratory laparotomy. After uneventful induction of anesthesia, a catheter was

placed in the radial artery for blood pressure monitoring. An internal jugular catheter had been placed 2 days earlier. Thirty-five minutes after the start of surgery, a gastrointestinal perforation was identified as the underlying cause for peritonitis. At this point, the patient had a systolic arterial blood pressure of 95 mmHg and a heart rate of 105 beats/min despite administration of low doses of noradrenaline and 1,000 ml of crystalloids. The surgeons mentioned a diffuse bleeding tendency, and the resident started to administer fresh frozen plasma. Two minutes after starting the fresh frozen plasma, he noticed that the blood pressure had decreased substantially and that the heart rate had increased further. He looked at the surgical field and asked the surgeons whether there was any acute and uncontrolled severe bleeding. The surgeons answered in the negative. In the belief that an acute bacteremia was compromising hemodynamic stability, the resident increased the doses of noradrenaline. However, the systolic blood pressure remained low at 60 mmHg, even at a dose of 2 µg kg^{-1} min^{-1} of noradrenaline. At this point, he called for the senior attending anesthetist. At the same time, he noticed that the electrocardiogram ST segment was becoming progressively more depressed. He increased the fraction of inspired oxygen to 1.0. The resident informed the surgeons about the severe problems in maintaining blood pressure and about relevant changes in the electrocardiogram. He also indicated that a myocardial infarction could be the cause of this constellation and advised the surgeons to be prepared to perform chest compressions. A nurse was requested to prepare adrenaline for both bolus injections and continuous administration. Some minutes later, the senior anesthetist entered the operating room and, after a short phase of orientation, advised the resident to administer adrenaline. At the moment of injecting adrenaline into the central venous line, the resident noticed severe urticaria in the skin in the vicinity of the central venous line. He immediately communicated this finding to the senior attending anesthetist, and the diagnosis of anaphylactic shock caused by fresh frozen plasma was made. After administration of histamine blockers and glucocorticoids, the remainder of the surgical procedure was uneventful and the patient recovered without any neurologic deficits.

Individual SA

SA Level I

SA level I (*perception* of the patient's state) was formed in the aforementioned case by collecting relevant information from monitoring the patient's vital parameters (low blood pressure, heart rate, oxygen saturation, electrocardiogram), the surgical field (no bleeding), and the appearance of the patient (urticaria). Additional information was acquired through communication with the team (bleeding tendency, intestinal perforation, no acute severe bleeding).

A patient's condition is often static or changes very slowly during the maintenance phase of uneventful anesthesia.

However, during induction and emergence from anesthesia or during a critical incident, they may change substantially in a very dynamic manner. The appropriate distribution of attention during such events determines the sensory input to the anesthetist and is therefore an important underlying process of SA level I.[7–9] In terms of the critical incident described above, a failure of attention would have occurred if the anesthetist had not noted the urticaria (SA level I) during the administration of adrenaline *via* the central venous catheter, even though this sign had been within his perceptual field. Such failures occur because of attention being directed at other information that appears more relevant.

SA Level II

SA level II encompasses the anesthetist's comprehension and understanding of these variables. Accordingly, anesthetists integrate SA level I knowledge with their long-term memory about medical knowledge, medical guidelines, mental models of physiology and pharmacology, and alterations of the physiologic state by specific surgical procedures. With good level II SA, the anesthetists would recognize that anaphylactic shock is the cause of the low blood pressure and urticaria. Together with the senior anesthetist, the correct diagnosis was made based on the patient's state and the underlying data. Thus, SA is more than perceiving data, it is integrating those data to understand what they mean and what is pertinent for the current situation.

SA Level III

SA level III is the highest level of SA and is the level at which anesthetists will project the expected future development of the patient's status, which is crucial for early and adequate proactive management of resources to meet the goals of therapy. In the Case Example, administering fresh frozen plasma to address a bleeding tendency and advising the surgeons to be prepared for chest compressions are examples of decisions and communication that emerge from SA level III.

In conclusion, the anesthetist's ability to actively direct their attention toward the main sources of information and to correctly understand and interpret the information they have at hand, enabling them to anticipate the future development of the case, plays a substantial role in treating critical incidents effectively.[1,4,9,10] SA is considered indispensable for subsequent decision-making, teamwork, and task management[3,5,8] and is therefore crucial for patient safety.

Team SA

Anesthetists are only one part of an interdisciplinary team of individuals engaged in the common project of "patient treatment." Therefore, the traditional SA concept where the object of interest is the cognitive process within the anesthetist's mind has been extended. The aim is to determine how and to what degree SA is present across a team (team SA) and to study the mechanisms that are used to share SA within
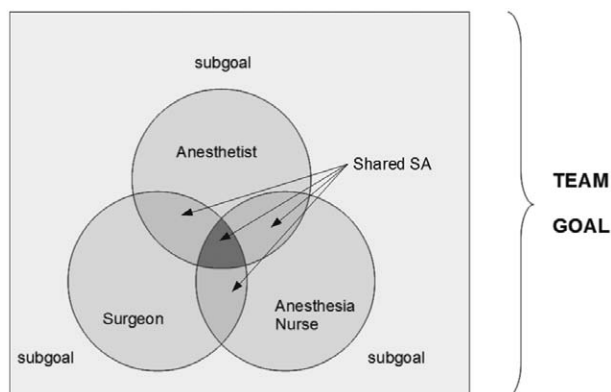
Fig. 1. Team situation awareness (SA) for a team consisting of anesthetist, surgeon, and anesthesia nurse. Each team member has individual subgoals that serve to reach a team goal. Shared SA evolves between them. This example refers to a situation where all members care for the same patient. (Adapted from Endsley MR: Towards a theory of situation awareness in dynamic systems. Hum Factors 1995; 37:32–64.)

and between teams. Team SA is defined as "the degree to which every team member possesses the SA required for his or her responsibilities."[2]

In this view, it is not sufficient that a team member has a piece of information; rather, it is necessary that each person be aware of circumstances that are relevant to their respective roles and responsibilities. However, not all the information needs to be shared with every involved individual. There would be cognitive overload if everyone's SA was entirely the same. Rather, effective team performance requires that SA is shared only for those subsets of the information that are relevant to selected team members. Shared SA is therefore defined as "the degree to which team members have the same SA on shared SA requirements" (fig. 1).[11]

In a highly effective team approach, decisions should be based on information derived from all team members. This allows for an efficient plan of action; otherwise, a breakdown of performance would occur when team members are not able to anticipate which help is needed by the others.[11,12]

According to Endsley and Jones, team SA is affected by the following: (1) shared SA requirements, which can be specifically defined for the team; (2) shared SA processes, including group prioritization and contingency planning, a group norm of information sharing and working to develop a common understanding, and active cross-checking and questioning of information across the team; (3) shared SA mechanisms (such as shared mental models among the team)[13,14]; and (4) shared SA displays (which can include auditory, visual, and other displays), verbal communication, nonverbal communications, and shared environment (fig. 2).[11] These factors come into play in building team SA both for teams that are co-located (such as in an operating room) or for teams distributed in time or space such as with a shift change or in a recovery room,

where team members may be coming and going (distributed team SA).

Referring to the critical incident described in the beginning of this section, the information about the developing urticaria was explicitly shared with the attending anesthetist (and not with the surgeons, although they may have perceived this information) with the aim of enhancing team SA. There was also cross-checking and questioning of information when asking whether there was acute severe bleeding. The patient monitor not only served for monitoring the patient but also was an important tool for sharing SA between the anesthetists. Finally, the team, consisting of two anesthetists, surgeons, and nurses, used shared mental models (differential diagnosis of shock, pathophysiology, and therapeutic goals) that made the development of team SA more efficient.

Recently, a successful transfer of team SA from theory into practice was undertaken by using the Surgical Safety Checklist for operating teams in a prospective multicenter study. In terms of team SA, fulfilling the checklist required the teams, among other things, to define a team goal and to actively share SA about the patient, the planned procedure, and potential critical events. Using this approach, Haynes *et al.* demonstrated reduced perioperative complications, fewer surgical-site infections, fewer unplanned returns to the operating room, and reduced mortality.[15]

Distributed SA

The model of individual and team SA is quite different from the concept of distributed SA (DSA) that was presented by Stanton *et al.* in 2006.[6,16] Stanton *et al.* argued that a concept of DSA that encompasses not an individual but a complex nonstatic system including human and nonhuman subsystems, and the interactions between them, may provide a better understanding of how certain output (performance) evolves from a team.[6] Accordingly, in distributed teamwork (*e.g.*, operating room), cognitive processes occur at a system level rather than an individual level.[6]

Recently, Fioratou *et al.* reviewed the DSA approach for its applicability in anesthesia.[10] The authors argued that anesthetist, surgeon, patient, and patient monitoring are subsystems that interact in a dynamic manner, permanently, and both implicitly and explicitly. For example, revealing the patient's state to the anesthetist, the anesthesia machine display is a physical mediator between the patient and the anesthetist and can be classified as an indirect communication device between them.[10] Fioratou *et al.* suggested that the traditional SA approach includes only simple patient monitoring for gaining SA and concluded that the DSA approach captures better the mechanisms that led to ineffectively distributed information. However, this statement is controversial because existing theories of SA and team SA clearly state that people gain much of their SA from the objects and tools in their environment, along with
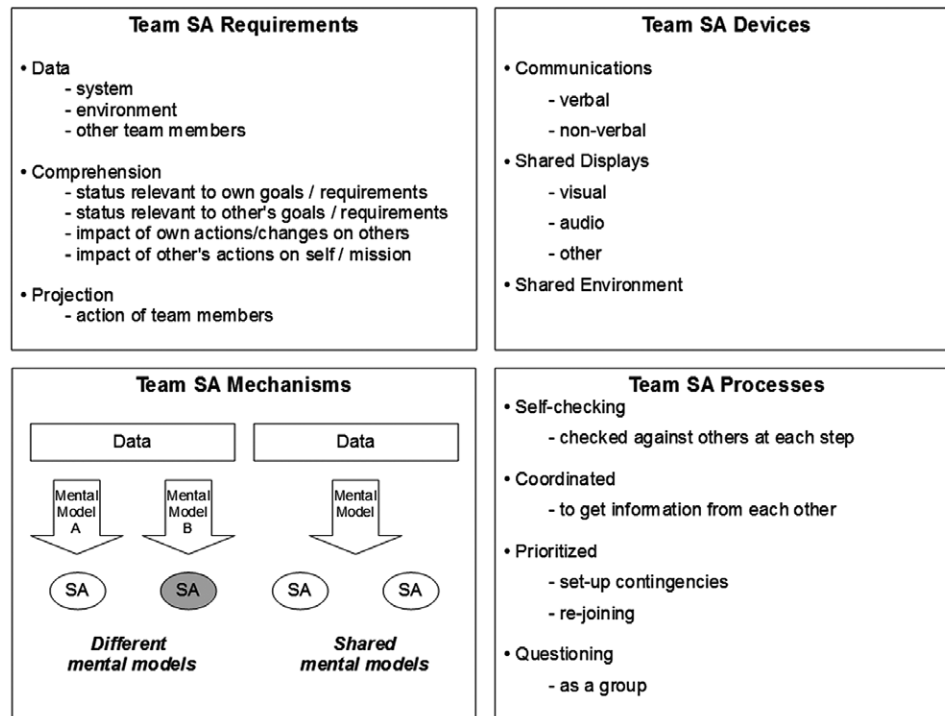
Fig. 2. Factors impacting team situation awareness (SA). (Modified from Endsley MR, Jones WM: A model of inter- and intrateam situation awareness: Implications for design, training and measurement, New trends in cooperative activities: Understanding system dynamics in complex environments. Edited by McNeese M, Salas E, Endsley MR. Santa Monica, Human Factors and Ergonomics Society, 2001, pp 46–67. Reproduced with friendly permission by the Human Factors and Ergonomics Society, Copyright 2001, All Rights Reserved.)

communications from other teammates and directly from the environment itself.[2]#

In the course of the critical incident described earlier under What Is SA?, the attending anesthetist monitored the electrocardiogram and, at a certain time point, advised the resident to administer adrenaline. During administration of the drug, the resident noticed urticaria and informed the consultant, at which point the assumed diagnosis was changed and adequate therapy was provided. In DSA parlance: (1) the "knowledge" within this system is distributed (some knowledge is provided by the patient him- or herself [urticaria], other knowledge is technically mediated [electrocardiogram] or provided by individuals in the team; and (2) there was implicit communication rather than active sharing of mental models about differential diagnoses to be considered. For illustration of the DSA perspective, another example of the involved subsystems in the system operating room and related interactions is given in figure 3.

In conclusion, DSA focuses at the system's SA and analyzes the interactions between the subsystems (human and nonhuman) to understand how SA evolves. In contrast, the traditional SA approach focuses on individuals who together

develop team SA and shared SA. The team SA model provides an explicit review of the various processes used by effective teams for gaining SA. Moreover, it describes additional ways in which teams can obtain shared SA of relevant information, such as by observing the same information in a shared environment or through effective shared mental models built up through training and common experience.

Assessment of SA

The assessment of SA from both simulation-based and clinical settings can be used to quantify training effects. It may thus provide an understanding of the factors contributing to SA. Below, we present different tools that have been used to assess SA in anesthesia or that may be suitable for anesthesia but have not been applied so far. There are both direct and indirect methods. Direct methods measure SA itself; indirect methods make use of process indices, behavior, and certain performance parameters that are considered to be indicators of SA.

Direct Measures of SA

Direct SA measures can be derived objectively or subjectively. A direct and objective SA measure that has been validated and applied across different domains, including the field of medicine, is the Situation Awareness Global Assessment Technique (SAGAT).[17–22] SAGAT was designed to assess the different levels of SA using scenario-specific questionnaires

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#Schulz CM, Kochs EF: Distributed situation awareness: What is really new? e-Letter to the Br J Anaesth 2012, published 19 March. Available at: http://bja.oxfordjournals.org/content/105/1/83.full/reply#brjana_el_8549. Accessed December 22, 2012.
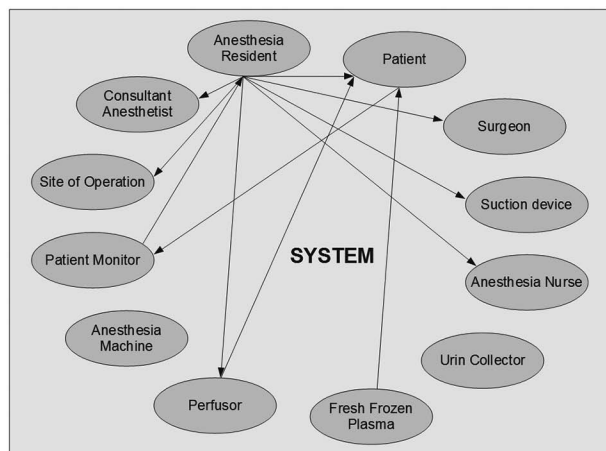
Fig. 3. In the distributed situation awareness approach, the whole system is considered to develop situation awareness, and after identifying the subsystems in this system, the interactions between the subsystems are the primary object of analysis. It consists of human and nonhuman subsystems that interact in different manners. The figure illustrates examples of subsystems in the system "operating room" and examples of interactions. The types of interactions between the subsystems varies: beginning with the administration of fresh frozen plasma, the fresh frozen plasma acted on the patient and the patient revealed his state to the patient monitor, which provided integrated information to the anesthesia resident. The resident consequently gathered information by looking at the surgical field and the suction device and by communicating to the surgeon. Apart from that, he called the consultant anesthetist and increased the dose of noradrenaline on the perfusor that acted in consequence on the patient.

when stopping at random points during a simulated scenario (table 1).

Only one reported study in the field of medicine validated a direct assessment of SA. Hogan *et al.* used SAGAT in an Advanced Trauma Life Support curriculum that investigated 16 volunteers with different levels of expertise.[18] Each subject had to resolve three different standardized scenarios. At random points, the scenarios were frozen and the subjects answered SAGAT questions that assessed their knowledge of each aspect of the situation that is relevant for SA. SAGAT scores were found to be significantly dependent on the subject's expertise and correlated significantly with traditional checklist performance scores.

The scenarios used in this study were designed for Advanced Trauma Life Support training and thus required the participants to use a highly standardized algorithm. In this setting, SAGAT provided good validity. A limitation with respect to describing the impact of SA on performance is that the correlation between SA and performance scores was not analyzed independently from the subject's expertise. Unfortunately, the authors did not specify the SA queries designed for each SA level. Thus, it remains unclear to what extent each SA level contributed to the overall SAGAT score. The process of designing and scoring SAGAT queries,

Table 1. Situation Awareness Global Assessment Technique

Level I (perception)
  How is the patient's blood pressure?
  Did the blood pressure decrease in the last 2 min?
  What medications have you administered?
  What is the dose of actually administered noradrenaline?
  What is the actual airway pressure?
  How much blood is in the suction device?
Level II (comprehension)
  Does the patient react adequately on your medications?
  Have you administered sufficient fluids?
  Does the patient have sufficient perfusion pressure?
  What is the reason for hemodynamic instability?
  What is the reason for ventricular extrasystoles?
Level III (projection)
  Do you expect the patient's blood pressure to increase, stay equal, or decrease?
  Do you expect the patient to suffer from a cardiac arrest?
  Do you expect the need to transfuse more fresh frozen plasma?

Examples of SAGAT queries that match on the illustrating critical incident. The answers have to be scored as either correct or incorrect basing on what was actually happening in the scenario. Normally, quantitative answers that differ less than 10% from actual values are considered correct.
SAGAT = Situation Awareness Global Assessment Technique.

especially in the more advanced levels of *comprehension* and *projection,* may be much more challenging for anesthesia critical incident training, where the scenario development depends on the decision-making process of the trainees. Another aspect of interest is the intrusiveness caused by the obligatory freezes of the scenario. In the study by Hogan *et al.*, only 12% of the participants were reported to be adversely affected by the freezes with respect to concentration and performance. Research in other domains confirms that the intrusiveness of the freeze procedure is negligible and does not affect objective performance measures in the simulation.[20,23–25]

Reader *et al.* used a completely different approach to directly investigate team SA.[26] Forty-four members of an intensive care unit were assessed for their accuracy in predicting patient outcome within the next 48 h (SA level III). For this purpose, the participants were asked to rate the likelihood of patient discharge, patient deterioration, need for ventilator support, and patient survival. These ratings were compared to the respective patient outcomes. This approach, which objectively scores SA, is similar to SAGAT. However, its application may be difficult in highly dynamic situations, where changes occur within minutes rather than days such as is the case during critical incidents in anesthesia.

In other domains outside of health care, subjective SA measures have been developed and were compared to SAGAT with respect to validity and reliability.[27–29] The Situation Awareness Rating Technique is such a tool.[30] Participants

Table 2. Situation Awareness Rating Technique

Familiarity of the situation
Focusing of attention
Information quantity
Information quality
Instability of the situation
Concentration of attention
Complexity of the situation
Variability of the situation
Arousal
Spare mental capacity

The Situation Awareness Rating Technique uses 10 different dimensions.

rate *post hoc* 10 dimensions (table 2) on a seven-point Likert scale, with the endpoints 1 = low and 7 = high. The tool is nonintrusive and uses queries that are not required to be adapted to scenario content. *Post hoc* ratings allow its application in clinical settings. These are major advantages for use in anesthesia. However, SA measured subjectively through the Situation Awareness Rating Technique was found to have no correlation with objectively measured SA using SAGAT.[31] Therefore, significant concerns with respect to content validity and sensitivity of the Situation Awareness Rating Technique[29,31,32] and a high correlation with workload measures have been raised.[33,34]

A major problem of retrospective self-ratings of SA is that the subjects may have acquired significant additional knowledge about scenario content on the *comprehension* and *perception* level of SA after having resolved a specific scenario. This is thought to be an important source of bias.[8,10,17] In addition, people are often unaware of their incorrect assessment or of missed key information (*i.e.*, they don't know what they don't know), thus limiting the validity of their ratings.[8]

In principle, SA can be assessed objectively and directly in anesthesia using SAGAT. However, valid SAGAT queries that investigate SA in dynamic decision-making–dependent anesthesia scenarios must be developed. Because SAGAT requires freezing the situation, it is only suitable in simulation environments. Subjective ratings are less intrusive but may suffer from insufficient validity. In real-world settings, other techniques may be preferable, such as concurrent probes,[32] that provide SAGAT-like queries verbally one at a time during the simulation without freezing the scenario; or process measures, which are discussed in the next paragraphs. Vidulich, by reviewing a wide number of studies using SAGAT, found that it had good sensitivity and provided detailed diagnostic information beyond what was available from performance measures alone.[35]

Assessment of Behavior as an Indirect Indicator of SA

The ANTS scale was designed and validated for the global assessment of nontechnical skills and evaluates behavioral markers of SA.[5] Trained observers use a standardized questionnaire to rate the participants.[36–38] One of four subcategories evaluates behavior (gathering information, recognizing and understanding, anticipating) related to SA. This scale has been used to assess training effects[39,40] and to compare the effectiveness of different debriefing methods.[41–44] A major limitation of the ANTS scale is that interrater reliability varies widely across studies.[36,39] This is most likely attributable to difficulties in handling the scale and differences in the quality of observer training. Two days of training are recommended for raters who are already familiar with the concept of nontechnical skills.[38]

Another scale applicable to the subjective evaluation of nontechnical skills is the Ottawa Global Rating Scale, which is a seven-point Likert scale with one item designated to assess SA.[45,46] Compared with the ANTS scale, data about validity and interrater reliability are scarce.

Both the ANTS scale and the Ottawa Global Rating Scale use observer ratings and are applicable in clinical settings. They are intended to assess nontechnical skills in general and are not designed to specifically assess SA. So far, it remains unclear to what extent the behavioral markers in these scales provide an independent assessment of SA and whether the observer ratings may be influenced by ratings on the other aspects of the scales (decision-making, teamwork, and task management). Future research is needed to validate SA-related behavioral rating scales against direct measures of SA in medical settings.

In another analysis of behavior, apart from the above-mentioned rating scales, Hazlehurst *et al.*[47] described how SA evolved from coordinated communication between surgeon and perfusionist during cardiac surgery. The authors identified six types of verbal exchange (*i.e.*, direction, status, alert, goal-sharing, problem-solving, and explanation) that facilitated team performance by enhancing SA. This is an example of research that examines SA processes but not the level or quality of SA achieved.

Assessment of Performance as an Indirect Indicator of SA

According to Endsley's theory of SA and the findings of Hogan *et al.*,[1,8,18,29] good performance is generally based on good SA (unless one is very lucky). In anesthesia, a variety of measures have been applied to assess performance. Simulation technology provides highly realistic work environments that permit comparative evaluation of performance using standardized scenarios.[48] In a variety of studies, including pediatric anesthesia,[49–52] checklists have been applied to assess the quantity of key diagnostic and therapeutic tasks. Other measures of potential interest[53] are the assessment of simulated patient outcome[54,55] or the time between the onset of a problem and its detection or definitive treatment.[56–59] Although such studies are useful for assessing the overall performance associated with a new display or training curricula, they do not directly provide information about the subject's SA itself and the features of the displays.[20,35]

Assessment of Gaze Behavior as an SA Process Measure

SA may also be inferred from techniques such as eye tracking to understand the types of processes that people use to gather information within their environment. It can be used to determine whether attention is given to specific data that are relevant for developing accurate SA. The idea is that particular information-gathering techniques may be more effective than others, and that understanding what the person is viewing (or neglecting to view) can provide insights into their SA.

For example, Liu *et al.* observed anesthetists' gaze behavior to assess the impact of a head-mounted holographic display of monitoring data on the distribution of visual attention. Similar to their simulation study,[58] the participants with the head-mounted display spent more time looking at the patient and the surgical field and less time looking at the monitoring equipment because the principal information was available without looking at the patient monitor.[60] However, observation of video recordings of gaze direction may lack sufficient accuracy to assess SA because the observer cannot differentiate whether the participants looked at the patient or at the parameters provided by the head-mounted display that are projected and overlap the patient in space.

Recently, a head-mounted eye-tracking device has been used to objectively assess visual attention as an underlying process of SA during simulated critical incidents.[9] Whether a critical incident occurred or not had a significant impact on how visual attention was distributed. This study showed that gaze behavior is adapted to the needs of developing and maintaining SA and that this adoption processes depend on experience.

Thus, the anesthetist's distribution of visual attention determines what is in the anesthetist's perceptual field and therefore contributes to the sensory input. Eye tracking provides an objective assessment of visual attention with high temporal and spatial resolution. How and to what extent expertise influences gaze behavior and whether there is a specific gaze behavior that is optimized to enhance SA in anesthesiology remains unclear and requires further investigation. So far, eye tracking and other SA measures have not been applied together in studies of healthcare providers. A combination of eye tracking and SAGAT could simultaneously determine what information had been *seen* and to what degree this information had been *perceived* and *comprehended* by the individual. In other fields, eye tracking has been used to study inattentional blindness with respect to eye movements.[61,62]

Expertise

Anesthetists (and physicians of all other specialties) establish SA in part through information available from displays, direct observation, and communication with the team. It is evident that the way information is gathered and processed is highly dependent on expertise.[18,63] Obviously, some anesthetists are much more capable of gaining high SA levels, whereas others may make insufficient use out of the same information. A 10-fold difference in SA levels was found

across 25 highly experienced pilots; that is, the SA of the pilot with the highest score was 10 times that of the lowest scoring pilot.[63] This significant range in SA scores was found to be highly reliable, with test–retest ratios of 0.99, 0.98, 0.98, and 0.92 on four pilots who participated in comparable sets of 24 simulation trials. These differences were found to be attributable to differences in cognitive capabilities, including attention-sharing abilities, pattern-matching abilities, and spatial abilities. In addition, the knowledge bases and skills that are acquired with training and experience are very important for the effective development of SA. Experts are characterized by their ability to gain SA with less effort, faster, and more completely, and will achieve higher levels of comprehension and projection.[64]

The SA model suggests the following individual factors that determine whether good SA is achieved[64]:

1. *Capacity*: Each individual has a limited capacity to attend to all the relevant information.
2. *Working memory*: Developing SA requires the working memory to store, integrate, and process the perceived information and to continuously update the current mental model of what is happening. As working memory's capacity is exceeded, critical information may be forgotten or may not be properly integrated for development of SA at higher levels.
3. *Goal-driven processing alternating with data-driven processing:* In a top-down goal-driven process, the anesthetist's goal (the ideal state of the patient) will direct which aspects of the environment are attended to. In a bottom-up data-driven process, the anesthetist's attention is distributed across all relevant information and his or her attention will be captured by salient or key information that may indicate that the strategy to reach a goal has to be changed or to change the goal itself. Endsley considers an ongoing cycling between goal-driven and data-driven processing to be a key feature underlying SA. The importance of this is taught in Anesthesia Crisis Resource Management training: to reevaluate a situation at regular intervals.
4. *Expectation:* Expectations, whether justified or not, affect the visual search for information, the *perception* of that information and, as a consequence, the higher levels of SA.
5. *Mental models:* These consist of cognitive mechanisms for interpreting and projecting events in complex domains. They are part of the long-term memory and serve to circumvent the limitations of the working memory.[1,2,64] During the introductory Case Example described earlier, a useful mental model may have comprised the five or six differential diagnoses of the causes of shock with its typical signs. If the anesthetist possesses such a mental model, he or she might have actively searched for urticaria to verify or exclude this

diagnosis but would not have to figure out the meaning of observed urticaria in the working memory.

6. *Pattern matching:* In a demanding situation that is similar to a prior episode, the process of developing good SA will be faster, because much information associated with this prior episode can be recalled. Cognitive workload is much less for anesthetists who have good pattern-matching abilities. In the Case Example, the resident saw the ST segment of the electrocardiogram becoming increasingly negative. Together with ventricular extrasystoles and a low blood pressure, he or she may have had in mind a prior situation with a patient suffering from cardiogenic shock during his or her work as an emergency physician. Based on this experience, the resident immediately concluded that a myocardial infarction and cardiogenic shock were the cause of the patient's deterioration. Such pattern matching can be almost instantaneous and effortless.

7. *Automaticity:* Automaticity reduces the necessary cognitive load to perform a certain physical or cognitive task and thus frees up the mind, providing more resources for attention and working memory. For example, if the electrocardiogram suddenly becomes flat, a more experienced anesthetist may *automatically* look at the pulse

oximeter to verify whether the electrocardiogram is an artifact or truly represents an asystolic patient. Alternately, performing repetitive physical tasks, such as suturing, automatically leaves attention free for thinking about other problems during the operation. These actions can occur without using working memory, leaving it free for developing SA.

8. *Learned skills:* Finally, there are numerous learned skills that are domain-specific and that support the development of accurate SA; for example, medical students learn how to interpret specific alterations of the morphology of an electrocardiogram and to derive a diagnosis.

To bring all of the above items together, we have adapted the work of Endsley[2] and Gaba *et al.*[3] to create a framework of SA in health care that links SA to performance (fig. 4).

SA Errors

From a theoretical point of view,[2] failures in anesthesia, intensive care, and emergency medicine may occur at each SA level, and SA can be incomplete, inaccurate, or both: information may not be detected or gathered correctly (SA level I), or the situation is not understood, although all of the relevant information is detected (SA level II); or the future is not correctly
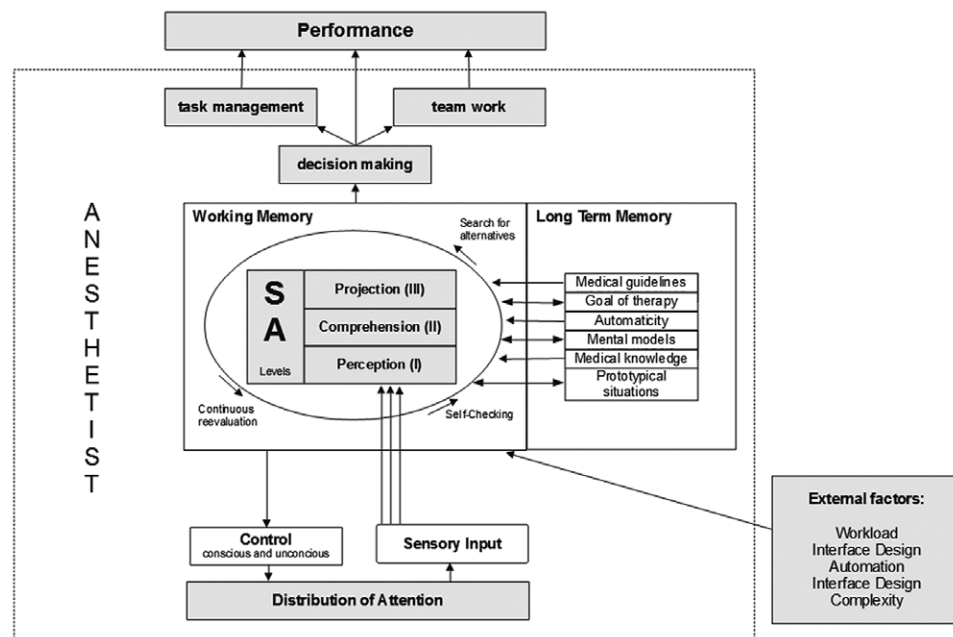
Fig. 4. A framework of the anesthetist's situation awareness (SA). (Adapted from Endsley MR: Towards a theory of situation awareness in dynamic systems. Hum Factors 1995; 37:32–64; and Gaba DM, Howard SK, Small SD: Situation awareness in anesthesiology. Hum Factors 1995; 37:20–31.) The framework illustrates that SA is central for decision-making and thus performance. The perception level is determined by the sensory input and the sensory input evolves from how attention is distributed, consciously and unconsciously. SA at higher levels is achieved by integrating the perceived data with information from the long-term memory such as medical guidelines, goals of therapy, mental models, medical knowledge in general, and by pattern matching with prototypical situations. There are also a variety of external factors that may influence, positively and negatively, whether adequate levels of SA are acquired. As a situation changes over time, a continuous reevaluation of the situation is obligatory to have actual SA. Dimensions in the *gray fields* have been assessed in the literature related to SA, illustrating that multiple factors that influence SA or are associated with SA can be assessed simultaneously in the same simulation session, such as SA,[17,19,21] workload,[83–85] behavior,[2] visual attention,[9,86] and performance.[48]

anticipated, although the situation is understood (SA level III). Consequently, affected SA elements that are involved in decision-making may lead to poor performance.

SA Level I

In SA level I, the anesthetist fails to perceive relevant information (incomplete SA). This type of error can result from a lack of detectability (*e.g.*, because of a visual barrier or auditory masking), it can be a failure of the system design to make the information available, or the information is available but not attended to for various reasons. In the course of the illustrative critical incident, the anesthetist did not notice the urticaria because of a visual barrier. Another type of error at level I is inaccurate SA, in which a perceived value does not represent reality. For example, during carbon monoxide intoxication, the measured and thus perceived values of oxygen saturation may be falsely high as assessed by pulse oximetry. The data may all be present, but the attention of the anesthetist is focused on only a subset of it, neglecting important data. In other cases, a syringe may be misread and a wrong drug administered because the labeling is very similar to that of another drug.

SA Level II

SA level II errors occur when available cues are not integrated and understood correctly. Similar to level I, SA at level II can be either incomplete or inaccurate. Endsley discussed a variety of contributing reasons: missing mental models, selecting the wrong mental model, or a failure to recognize prototypical situations. Klein described errors in medical decision-making that evolved from interpreting a combination of successive signs into an existing diagnosis even though the symptoms clearly indicated a different diagnosis.[65] This is an example of using a wrong mental model to interpret information. If there is no mental model available for a given situation because it is new to the anesthetist (missing mental model), SA level II has to be developed in the working memory and errors can occur because of working memory limitations, especially under high cognitive workload. The individual simply cannot figure out what is happening fast enough during an event that has never been encountered before.

SA Level III

The prediction of a future state is incomplete or inaccurate even though the current situation is fully understood. An example is when the anesthetist fails to consider that a blood transfusion may be necessary based on the type of operation and therefore blood products are not ordered in a timely manner. In another case, the anesthetist may not consider the likelihood of a cardiac event even though the decreasing blood pressure and related electrocardiographic problems are clearly noted.

For novices, gaining adequate SA is very demanding and frequently incomplete, and may be faulty because of limited

attention and working memory capacities or less developed mental models. How can we make them experts in SA abilities?

Training

To date, it remains largely unclear how and to what extent relevant skills for the development of SA are acquired and what type of training should be implemented to achieve an optimal increase in SA abilities in healthcare providers. To some degree, some of the individual factors that facilitate the development of SA are taught during residency and other training forums such as Anesthesia Crisis Resource Management training.

In a first attempt to develop and evaluate a formal training of SA in anesthesia in final-year medical students, a recent study[21] used SAGAT during simulated scenarios of severe sepsis in a pretest/posttest design. The effects of the simulator training were compared to a classroom-based approach to train SA skills. During the debriefing of the simulator training, the diagnosis and treatment of sepsis based on the respective scenario was taught; however, no nontechnical skills, such as SA, were considered. The classroom-based approach consisted of a theoretical lecture about SA, a video-based discussion about the team's SA during a cardiac arrest situation, and different psychological exercises. With respect to SAGAT scores, the simulator training but not the classroom-based SA training was found to slightly improve participants' SA. In the SAGAT queries, comprehension questions were not considered, and projection questions were used only during the second scenario freeze.

In the past decade, there have been numerous efforts to implement formal SA training with the aim of enhancing performance in aviation and other domains.[66] These training approaches have attempted to improve cognitive skills and to build the cognitive structures that are necessary for high levels of SA. In the next paragraphs, we present training approaches that have been applied in other domains that may be considered for improving SA in anesthesia.

Classroom-based Instruction

One approach was to train individuals and teams about SA and hazards that evolve from inaccurate SA.[67] To realize this, a combination of classroom-based instruction and individual or team exercises was applied. Robinson,[68] for example, described a 2-day program for training pilots in SA that combined training on SA with error management strategies.[69,70] After receiving the training, the pilots were rated as having significantly better team skills and established significantly more SA at level III. Later, this program was implemented at two major European airlines. Ninety-nine percent of the pilots reported the training to be very useful, and the majority of them indicated that they were using the training during their daily work.[71]

Computer-based Training

Another approach focused on the underlying knowledge and skills for use of good SA by means of computer-based training programs that allow training of relevant cognitive mechanisms. McKenna and Crick improved SA level III in drivers by presenting video clips of driving scenes. During freezes, the trainees were encouraged to project what might happen next.[72,73] Bolstad *et al.* designed computer-based training modules to train specific basic skills in novice general aviation pilots. The modules addressed the training of checklist completion, communication, psychomotor skills, attention-sharing skills, preflight planning, and contingency planning.[74,75] Another example is the work of Strater *et al.*,[76] who presented a personal computer-based tool to improve SA in infantry officers. Using a multimedia computer-based approach, trainees were exposed to many situations within a short period with the aim of generating memory for prototypical situations and recognizing its critical cues. Moreover, the tool requested the trainees to make complex operational decisions using a "What? So what? Now what?" approach. That is, the trainees learned to think about their SA needs in terms of: *What* information do I have or do I still need? *So what* does this information mean in terms of my goals? *Now what* will happen next or what should I be prepared to deal with in the future situation?[76] In a study of this training approach, Strater *et al.* found that infantry leaders who received the training were significantly less likely to fall into traps in the testing scenario that would have had them attack a civilian refugee encampment.[76]

Virtual Environment Situation Awareness Review System

Another interesting approach applicable in anesthesia simulation environments is the Virtual Environment Situation Awareness Review System.[66] It consists of a behavioral rating tool that assesses individual as well as team actions, a communications rating tool that evaluates team communications, and an SA query tool that allows direct assessment of individual and team SA.[77,78] The rating results are presented in a postsession debriefing so that trainees understand the degree to which they actually were or were not able to form SA during specific events and why. This is thought to provide a more effective debriefing method with respect to SA training, as this creates a useful template for the debriefers and provides actionable feedback. Initial testing of this approach received positive subjective ratings from participants regarding the tool utility, but it has not yet been validated extensively.[66]

Training Principles

Important training principles[66] include training in task management and prioritizing, self-checking behaviors, basic skills to find the relevant information, common types of SA errors, attention-sharing ability, critical behaviors and communication that are essential for team SA, development of mental models, and feedback on how good or poor the trainee's SA is along with ideas for improvement, building better mental models to develop team SA more directly, and training teams in cross-checking their SA.

Interested readers are referred to the threat and error management systems approach that was developed with the aim of improving aviation safety. This approach provides a framework for understanding the role of human factors in complex dynamic environments and describes additional training principles that support the establishment of a safety culture.[79]

Applicability in Anesthesia

The findings from a single study in anesthesia,[21] but also from other domains such as aviation, suggest that focused SA training is a promising approach for increasing healthcare providers' ability to form individual SA and team SA and thus to promote better performance during patient care. All of the aforementioned approaches seem applicable in anesthesia. Apart from that, anesthesia can draw on more than two decades of experience in high-fidelity patient simulation and related debriefing techniques that are valuable tools for SA training.

These approaches go far beyond Anesthesia Crisis Resource Management training. Although Anesthesia Crisis Resource Management training includes a discussion of SA as an important factor, SA training focuses extensively on the development of key cognitive knowledge and skills that actually can increase levels of SA. A first step toward SA training in anesthesia may consist of providing theoretical knowledge about the concept of SA and thus sensitizing anesthetists to the factors that either compromise or convey the development of SA. For the implementation of formal SA training in a simulation-based setting, the debriefing should focus on the skills and behaviors that are associated with good SA. Computer-based training techniques as discussed above can be adapted for the challenges of SA in anesthesia. However, detailed and systematic research on common and critical problems that affect SA in health care is currently lacking. Therefore, the implementation of domain-specific and therefore goal-directed SA training in anesthesia still requires considerable research.

Displays of Patient Monitors

Observing the patient monitor, especially during dynamic phases of the operation, is an important but time-consuming activity and is a matter of routine during anesthesia.[9] As stated earlier, the patient monitors provide much relevant information required for establishment of accurate SA. Therefore, another field of great interest and of growing scientific effort addresses the design of patient monitors.

To date, the patient monitors in routine use are based almost exclusively on the single-sensor single-indicator design. With such displays, anesthetists must monitor multiple variables and mentally integrate them to obtain the

actual status of the patient's situation. With limited attention and working memory, this can become overloading, particularly in highly dynamic situations, or can create vigilance problems in other cases.[80] Thus, as more single-sensor single-indicator variables are added to the monitor screens, the expected increase in SA is doubtful.[80]

With the objective of overcoming these limitations, several empiric studies have attempted to enhance SA by providing additional or modified monitoring devices that assess performance but not SA itself. In 2008, Görges and Staggers reviewed studies that evaluated different physiologic monitoring displays.[56] In 18 of 31 studies, the participant's performance, assessed as time to detect or time to make a diagnosis or time to clinical decision, was found to be superior with a novel display using graphs or sounds. Accuracy in clinical diagnosis and decision-making was improved in 13 of 19 studies.[56]

In a more recent study, Charabati *et al.*[57] compared four different graphic display designs for a monitoring system that presented integrated data with the aim of providing information about the depth of analgesia, hypnosis, and neuromuscular blockade. The primary outcome parameter was the time to detect and correctly verbalize the problem, and a secondary outcome parameter was workload assessed by the National Aeronautics and Space Administration Task Load Index. With a combined numeric–graphic display, the detection times were significantly shorter and the workload was lower. Interestingly, this display resembled mostly the traditional single-sensor single-indicator design consisting of a split screen with curves on the left side and numeric values on the right side.

In another attempt to enhance anesthetists' SA, Liu *et al.* and Sanderson *et al.* investigated auditory displays and head-mounted displays in simulator environments[58,59] and in the real operating room.[60] The auditory displays increased the number of potentially harmful events detected,[58] whereas the head-mounted display did not result in the detection of more events or in a faster detection of those.[58,59] Distracted anesthetists wearing a head-mounted display detected events even more slowly. According to the authors, this can probably be attributed to inattentional blindness.[58] Head-mounted displays can inadvertently occlude information because of both visual interference and attentional shifts associated with these displays, thus reducing their benefit for many applications.[81]

Apart from these studies that used performance markers to investigate the impact of new monitoring devices, two studies have been conducted in anesthesia that evaluated the impact of new monitoring devices using SAGAT. With respect to anesthetists' SA, Zhang *et al.* compared a traditional single-sensor single-indicator display and an object display that showed functional cardiovascular physiology by the integration of hemodynamic variables.[19] Four simulated test scenarios consisting of myocardial ischemia, arrhythmia, hypovolemia, and bronchospasm were designed. The authors

did not find the object display to be superior with respect to SA and performance. It was assumed that the general unfamiliarity with the object display even after a training period posed a major problem. As a limitation, the SAGAT queries used by Zhang *et al.* did not include *projection* queries.

In another attempt to enhance SA, Ford *et al.*[17] tested a vibrotactile belt that vibrated at four different points indicating changes in ventilation volumes and pressures. The hypothesis tested was that the belt would enhance the anesthetist's SA by providing information in a way that could be processed simultaneously with the highly loaded visual sense and therefore result in better performance during the management of an anaphylactic reaction. The vibrotactile group was found to administer epinephrine significantly faster than the control group. Interestingly, no differences in SA were detected between the two groups. A limitation was that SA was measured using SAGAT in a *post hoc* assessment based on viewing interrupted video recordings on a split screen that showed the participants acting in the simulator environment and the simulator's vital signs. When SAGAT is used for a post-trial assessment, there is some risk of bias, particularly for assessment of the higher SA levels, because the subjects' knowledge about the scenario content and development is higher when the scenario completed. *Post hoc* assessment is also limited in that it can only reliably collect SA at the end of the trial.

Kiefer and Hoeft mentioned the methodologic shortcomings of studies that investigated new displays because of very short instruction times. Instead, the authors suggested several months of training and use before unbiased testing.[80] Endsley and Jones recommended that the traditional display presentation (SA level I data) also should remain available along with such integrated displays, as one still needs to be able to understand individual parameters when digging deeper into situations.[82]

Synthesis

Good SA is crucial for decision-making, which leads to increased performance in patient treatment during anesthesia, intensive care, and emergency medicine. So far, limited attention has been paid to systematic research about SA in anesthesia. The ability to develop SA accurately, completely, and quickly increases with the anesthetist's expertise. Important skills needed for this process are acquired with experience and training. A key point is that it is possible to more rapidly and consistently boost these skills and thus performance by focused training that is specifically designed to improve specific SA skills. For the development of formal SA training programs, it is a prerequisite to first identify anesthesia-specific factors that may affect individual and team SA in both research and clinical settings, so that such training programs can be tailored appropriately. More research on the role of SA in anesthesiology, both in simulations and in real work environments, that use direct and objective measures of SA and performance are needed to help support this process.

The design of tools for information presentation in health care can increase SA and constitutes another field of potential development. In this review, we focused briefly on the design of patient monitors and discussed studies that demonstrated increased performance because of novel displays. Facilitating the development of SA should be a primary target when new monitor displays are designed. Research from other domains demonstrates that displays can directly provide information on level II SA and level III SA, thus reducing both workload and errors.[82] In anesthesia, low-level data could be embedded in physiology-based models, for example, to provide a more intelligent presentation of information (*e.g.*, graphically and in only one region of interest, thus reducing the anesthetist's workload). Another attempt may consist of providing information that directly represents SA at higher levels by integrating the single-sensor single-indicator data using physiologic models—that would be a monitor that "understands" the patient's state to a certain degree and can support comprehension and projection.

In conclusion, SA has to be recognized as a critical component of decision-making that has a direct effect on performance in medical care. A variety of skills and behaviors that influence SA have been described that are based on research from a wide variety of domains. These findings are generally transferable and applicable to anesthesia, but domain-specific factors that are important for SA in this domain have not yet been investigated. Thus, there is an opportunity and a need for much more research in the perioperative setting in terms of individual SA and in terms of team SA. Because all of our decisions are based thereupon, the development and evaluation of new technology should take into account the effects on SA. Finally, various training approaches from other domains designed to improve SA abilities can be adapted to the needs in anesthesia to more rapidly improve this important competency in anesthetists.

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