BJA

Beyond monitoring: distributed situation awareness in anaesthesia

E. Fioratou[1*], R. Flin[1], R. Glavin[2] and R. Patey[3]

[1] Industrial Psychology Research Centre, School of Psychology, University of Aberdeen, King's College, Old Aberdeen AB242UB, UK
[2] Victoria Infirmary, Glasgow, UK
[3] Aberdeen Royal Infirmary, Aberdeen, UK

* Corresponding author. E-mail: e.fioratou@abdn.ac.uk

Key points

- Situation awareness is a vital non-technical skill.
- The anaesthetist forms part of a distributed cognitive system.
- SA emerges from the interactions in the operating theatre.
- DSA could illuminate anaesthetic practice and training and suggest future research.

Summary. Situation awareness (SA) is one of the essential non-technical skills for effective and safe practice in high-risk industries, such as healthcare; yet, there is limited research of its significance in anaesthetic practice. In this paper, we review this scant research that focuses on SA as patient monitoring alone and advocate for a more comprehensive view of SA in anaesthetic practice and training that extends beyond monitoring, namely, a distributed cognition approach. We identify further factors influencing anaesthetists' SA and provide a case that resulted in an anaesthetic fatality to illustrate the application of an alternative view of SA in anaesthesia. Distributed SA in anaesthetic practice provides the foundation for further research that may in turn influence the teaching and assessment of this important non-technical skill.

Keywords: anaesthesia; monitoring, intraoperative; risk management; safety management; task performance and analysis

The operating theatre is a workplace fraught with information, in displays, records, technologies, and from team members. Anaesthetists need to be flexibly vigilant in their patient management by switching attention in a timely fashion to relevant information in order to make optimal decisions. Therefore, patient safety is highly dependent on the anaesthetist's situation awareness (SA), before operation, intraoperatively, and after operation.

SA is usually defined as: 'the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and a projection of their status in the near future'.[1] This definition, used across many professional areas, emphasizes the cognitive processes which are all 'in the head'. In fact, to adequately define SA for anaesthetists, we need to understand what it is about the 'situation' of which the anaesthetist must be aware.[2] Three key aspects have been identified:[3] (i) detection and interpretation of situational cues from multiple, dynamically changing data streams, (ii) adaptation to an evolving situation, and (iii) keeping track of and utilizing special elements of knowledge. Embedded within these are information sources from the patient, the rest of the operating theatre team, and the technology.

The Anaesthetists' Non-Technical Skills (ANTS) taxonomy[4–7] provides a broader definition of SA that captures the main components: 'Developing and maintaining an overall dynamic awareness of the situation based on perceiving the elements of the theatre environment: patient, team, time, displays, equipment, understanding what they mean and thinking ahead about what could happen in the near future'.[6] Thus, the unit of analysis should not just be the agent (anaesthetist) but the interaction of the agent with its environment that allows assessment of the agent's adapted behaviour.[8]

In this paper, we argue that SA is best understood at the level of this anaesthetist–environment relationship. Consequently, SA is viewed as being grounded in and emergent from the interactions over time of anaesthetists with both external artifacts and people towards specific functional goals. We favour a Distributed Cognition approach,[9] as it has been applied in healthcare[10–12] and in SA.[13 14] We believe that this enriches our understanding of the factors influencing anaesthetists' SA and consequent effects on the safety and efficiency of patient management.

We begin by reviewing the traditional view of SA and then explaining the advantages of using a distributed approach to SA (henceforth, DSA) in anaesthesia. Then, we consider two empirical studies that focus on monitoring and discuss how a DSA approach could complement their design and conclusions. We then present an anaesthetic case to illustrate this DSA perspective and suggest some research pertinent to the teaching and assessment of this non-technical skill.

DSA in anaesthesia

The conventional model of SA[1] is one of an agent generating a mental model based on the flow of information received by

that agent. During anaesthesia, an anaesthetist will use the information displayed in the patient monitors, such as heart rate, non-invasive arterial pressure, end-tidal CO_2, and Sp_{O_2} to generate a model of the patient's state. As this information changes and is processed by the anaesthetist, the mental model changes. The conventional approach to studying the generation of this mental model is to look at the cognitive processes involved. The focus of study is the mind of the anaesthetist. The physical or social environment in which these cognitive processes are taking place is not the focus of study, merely a source of information to be processed.

In contrast, the DSA approach emphasizes the continuous, mutually altering interaction between the environment and the anaesthetist. For example, when the anaesthetist acts on a physiological change in the patient's condition, such as an increase in arterial pressure, the patient's condition is changed. The arterial pressure may now decrease, stay the same, or increase further, but this condition has been influenced by whatever action the anaesthetist has taken. Thus, the strategies being used by the anaesthetists are influenced by their previous actions and the subsequent responses to these actions. Upon acting in an attempt to solve a problem, the problem itself changes, thereby affecting the strategy being used to solve it. There is a dynamic interplay between the nature of the problem and the actions taken to solve it.[15]

The traditional model of cognition was based on a 'black box' in the mind of the anaesthetist. All of the components of this model were contained within this 'black box'. Understanding medical decision-making from a distributed cognition approach has been advocated,[12] by arguing that external artifacts and other people transform the decision process and constitute a distributed cognitive system. In DSA, the unit of analysis is a distributed cognitive system composed of a group of people interacting with external artifacts. Table 1 demonstrates the key differences between the traditional SA and DSA models as we have applied them to anaesthetic practice.

To illustrate further, continuing with our high arterial pressure example, other members of the operating theatre team may not yet be aware that there is a problem. The addition of further information from a member of the team ('the patient is moving') will alter the anaesthetist's sense of what is happening. The anaesthetist may now have narrowed down possible causes for the increase in arterial pressure but may not fully understand why such a situation has arisen. Perhaps, the i.v. line into which the anaesthetist was administering neuromuscular blocking agents was blocked or one of the electrodes for the nerve stimulator used to monitor neuromuscular block had become detached. Detailed knowledge of any one of these components would not be enough to provide the overall state of what is happening. The person noticing these problems may not have the necessary knowledge and structure in their mind to explain what is happening. The anaesthetists may have the necessary internal knowledge and structure but unless the knowledge and structure in the environment is utilized, they may not be able to address the problem in a satisfactory manner. Such a distributed system can have cognitive properties that differ radically from the cognitive properties of its individual components. The distributed system properties cannot be inferred from the properties of the individual components, no matter how much detail we have about each component.[9] It is only when the interactions between all the individual components are put together that a coherent picture emerges. Internal representations (the knowledge and structure in individuals' minds) and external representations (the knowledge and structure in the external environment) have to be processed and appropriately integrated in order to acquire and maintain good DSA. Using our example, we can contrast the traditional SA model with the DSA model. From a traditional SA perspective, the focus of analysis would be the individual, in this case the anaesthetist. From a DSA approach, the focus of analysis would be the distributed cognitive system, in this case the interplay among the anaesthetist, other team members, the patient, and the external artifacts. Thus, a DSA perspective shifts our focus from the individual to an all encompassing distributed cognitive system. The DSA approach allows a better overall understanding of the operating theatre interactions and how they could foster or hinder anaesthetic practice. Consequently, we suggest that this approach could be utilized in training and research.

How can the elements and components in a distributed system—people, tools, charts, equipment, monitors, and less obvious resources—be coordinated to allow the system

Table 1 Key differences between the traditional SA model and the DSA model in anaesthetic practice

	SA	DSA
Unit of analysis	An individual anaesthetist	A distributed cognitive system, comprising the anaesthetist, patient, other members of the operating theatre, and external artifacts
Flow of information	One-way: into head of anaesthetist	Two-way iterative: the mental model influences actions; the results of the actions in turn influence the mental model
Source of information	The environment	The interaction(s) between the components of the environment
Area of study	The cognitive processes inside the head of the anaesthetist	The processes influencing the interaction between the components of the distributed cognitive system
Areas of research	The anaesthetist's internal representations Laboratory problem setting (experimental)	How internal and external representations interact in anaesthetic practice Real problem setting (ethnographic)

to accomplish its tasks? Cognitive scientists endeavour to explain the principles governing this distribution: principles of coordination, externalization, and interaction.[16] [17] The DSA approach for anaesthesia expands the three levels of SA[1] and follows earlier anaesthetic analyses.[6] [18] [19]

Level 1 SA: perception of the elements in the environment=detection

The anaesthetist has to be aware of the patient's progress through monitoring of the anaesthetic machine displays and directly from the patient (e.g. colour, sweat). At the same time, there is a need to be aware of the other team members (e.g. surgeon, nurses) and external artifacts (e.g. equipment, drugs). Thus, the notion of 'elements in the environment'[1] has to incorporate other people (dynamic element) and external artifacts (relatively static but can become dynamic, such as rapid collection of blood in the suction jar). Thus, the first step in achieving SA is to perceive the status, attributes, and dynamics of all the relevant 'elements' in the environment.

Level 2 SA: comprehension of the current situation=diagnosis

The anaesthetist has to synthesize and integrate all the information regarding the patient (knowledge of background pathophysiology and all the current information from monitoring the patient and how they have responded to events thus far) to identify the probable current state of the patient. Understanding the significance of a change in heart rate can be based on knowledge of the surgeon's recent procedure, drugs administered, or changes in other vital signs in order to establish whether this is an expected and temporary event or an unexpected and potentially serious problem. Again, understanding the current situation is achieved through knowledge accumulated from an interaction of the 'elements' in the environment. Thus, the second step in achieving SA is to understand the significance of objects and events in the environment by synthesizing the Level 1 elements in relation to towards one's current goal.

Level 3 SA: projection of future status=prediction

The anaesthetist has to anticipate the patient's response to anticipated drug administration or surgeon's procedure, including changes in vital signs, and to predict the surgeon's or nurses' requests. This projection is very important in allowing the anaesthetist to be proactive and not just reactive. It is achieved through knowledge of the status and dynamics of elements in the environment and comprehension of the situation (Levels 1 and 2 SA). Thus, projecting the future status of all the elements in the environment (again incorporating external artifacts and people) is the third and highest step in achieving SA.

The most common SA problems anaesthetists face have been identified as the detection of a change in the patient's physiological variables, the response to abnormal conditions, and the subsequent prioritization of corrective actions.[20]

However, this emphasis on monitoring the patient alone via displays does not give us the whole story: ensuring patient safety is also determined by careful monitoring of external artifacts (not directly related to the patient) and other people in the operating theatre (whose actions may have an impact on the patient). Detection of deviations from a monitored variable's expected value, prediction of future values or trends in these variables, and revision of the patient's state after an intervention or event[18] are important processes that any model of the anaesthetist's SA must account for, but they are not the only ones that need to be considered.

Obtaining desired information from anaesthetic monitors is challenging. We cannot accurately measure some indices that we would like to—depth of anaesthesia, adequacy of vital organ perfusion—for any one individual patient during all of the phases of perioperative care. We have to infer what is happening by applying general theories and experimental results obtained from populations of subjects in controlled settings to the particular patient under our care. However, the anaesthetist does have an opportunity to elaborate his or her knowledge of an individual patient by observing the physiological changes that occur with induction of anaesthesia and tracheal intubation. It has been hypothesized that the mastery of the subsequent anaesthetic management of the patient would be closely connected to the degree to which the anaesthetists took advantage of these opportunities for constructing a conception of that particular patient's physiological potentials.[21]

There are other important elements in the environment that guide anaesthetists' SA. For example, the anaesthetic machine displays become another mediator (physical) between patient and anaesthetist, an indirect communication device between them (one-way communication, of course, as the point is for the patients to 'communicate'/reveal their state to the anaesthetist), direct or indirect communication (symbolic) with the surgeon or nurses (for instance, through language or gestures or other embodied demonstrations) is another vital mediator. Interestingly (and perhaps unintentionally), an example of how SA emerges from others in the environment (without an explicit interaction) has already been provided.[3] A case was described where the surgeon provided information to the anaesthetist indirectly by placing a request to a nurse.[3]

Furthermore, in a primer of SA in anaesthesia,[22] an integration of information from different sources was advocated, extending beyond patient monitoring (including contact with the patient through the senses apart from the passive electronic monitoring), to include comments from the other team members in the operating theatre, and also historical aspects, such as the medical chart. It was demonstrated that in order to reach Level 2 SA, an anaesthetist needs to confirm a diagnosis or current state from multiple sources as well. For example, bradycardia may be confirmed by multiple monitors (pulse oximeter, ECG) and low oxygen saturation by direct observation of change in the patient's colour and the reading on the pulse oximeter.

Without SA being realized through action (actual action on the environment or a communication act), it would remain forever a mystery. With the help of DSA, we argue for a direct measure of SA via actions—when SA Level 1 is thought of as merely perception, we argue that perception is action[23] and thus equate SA with decision-making. According to this enactive view of perception, perception and its content become intimately linked to our actions in the world. The way the world appears to us becomes dependent on the particular way we are embodied and the history of our actions in the world.[24] When we perceive an 'element' in our environment and we direct our attention to it, we have already made a decision on its relevance. Thus, in naturalistic decision-making terms,[25] one could observe recognition-primed decisions and also decision-primed recognitions.[26]

SA in anaesthesia as monitoring: review and critique of current empirical studies

The only two empirical papers to date of SA in anaesthesia come from ergonomics[27 28] and seek to ascertain how anaesthesia information displays (3D-visual and vibrotactile, respectively) influence SA. In both studies, SA was defined as the anaesthetist's global mental representation of the current and future states of the patient, with SA Level 1 being the detection of changes in physiology, SA Level 2 being diagnosis of events, and SA Level 3 being predictions of future states of the patient. Comparisons were made between those new forms of display and the traditional displays in order to improve performance, as measured by response times and Situation Awareness Global Assessment Technique (SAGAT).[29]

When using SAGAT, a simulation is frozen at randomly determined points in time and participants are asked to answer task-relevant questions while being deprived of all task-relevant information (such as from the displays, which are usually blanked). This technique has been praised for dealing with two perennial problems, namely retrospective and concurrent measures. SAGAT eliminates any time-related and mental workload-related issues as its participants are tested during the task.[29]

In Study 1,[28] the traditional display was compared with an object display[30] using 12 anaesthetists with an average clinical experience of 6 yr (range 1–17), and in Study 2,[28] the traditional display was compared with a specially developed integrated 3D display using 12 first-year undergraduates of Bioengineering, with no experience of either display but with familiarity of the physiological signals and their meaning. Significant differences in SA were found due to type of display (faster reaction time, higher SA) but not for all the scenarios.[28] However, the relative difficulty of the scenarios could have been a confounding factor and only a small subset of queries was used (four Level 1 queries, two Level 2 queries, and two Level 3 queries), such that during the course of the experiment participants may have been able to predict the questions that would be asked for any given simulation freeze. Furthermore, the freeze occurred every 2.5 min, which would have been

easy for the participants to predict and the time allowed for each scenario was relatively short.[3]

Another issue with their studies was the measures they used. For Study 1, reaction time, event diagnosis time, and SA (via SAGAT) were used. The implication that reaction time is not a measure of SA is of course problematic. For example, the Situation Present Awareness Method (SPAM)[31] measures SA both as the number of correct responses to questions asked (e.g. during the course of an air traffic control simulation without scenario pauses) and as the time to answer the question correctly. Thus, with good SA, either task-relevant information or the location of this information is held in memory. Hence, even if the information is not in memory, but available on a display, response times would indicate whether the participant (in this case, the air traffic controller) can find the information. This is an indication of being 'situation aware'. We use the world as a memory store even for our most mundane tasks.[32] We do this because *that is where the information is*. We know it is there and return to it time and again—as needs dictate. Thus, we need to accept reaction time as an accurate measure of SA, as SPAM suggests.

In Study 2, SA Level 1 was measured by asking bioengineering undergraduates to mark on a checklist from memory whether the values for eight variables were high, normal, or low. In our view, this requires Level 2 SA as well. The fragmentation of SA is deceptively useful in theorizing but, in practice, it is blatantly illusory.

Turning to the more recent paper,[27] an embodied view of SA was provided, where vibrotactile displays were used to improve anaesthetists' performance on one simulated case of anaphylaxis. It was argued that the importance of this alternative modality cannot be overstated: in an emergency, where the cognitive load saturates the main sources of information, vision and hearing, relying on a different source, such as vibrotactility, frees cognitive resources to tackle the emergency. Furthermore, the vibrotactile displays offer an added value: comprehension of the meaning of a stimulus is embedded within its function, thus increasing the opportunity for correct diagnosis. This novel display was tested on 24 anaesthetists, comprising staff anaesthetists, anaesthesiology fellows, and fifth-year anaesthesiology residents with a minimum of 4 yr of clinical anaesthesia experience.

The results confirmed the authors' prediction with regard to response time to anaphylaxis: those in the vibrotactile condition were faster in delivering the right treatment (epinephrine) than those in the control group. However, paradoxically, this faster response time did not translate into a better SA, as measured in a *post hoc* SAGAT-type measure. Most probably, this was because SAGAT was specifically designed as a concurrent measure, thus adapting it for *post hoc* testing makes no sense. Having participants reviewing their video (their performance alongside the physiological variables display) after the event does not offer any data on their SA, it merely shows the effect of acquired knowledge from the simulation on their answers rather than their SA at the particular frozen moment. The authors,

in their attempt to get 'accurate' timing of the correct response (epinephrine administration), have sacrificed one SA measure by implementing SAGAT *post hoc*.

The use of SAGAT has been extensively discussed and criticized elsewhere in the literature.[33–35] In both anaesthesia studies,[27 28] response times are not considered to be relevant to SA but merely a separate measure of performance and SA is assessed by the percentage of correctly answered questions for the SAGAT scenarios. Thus, this defragmentation of 'performance' into SA and response time (knowing what is happening around one *vs* responding to the situation in a timely manner) is misleading. The SPAM[31] offers a better alternative: on one hand, if one holds the probed information in memory, then one will be able to respond quickly. On the other hand, if one does not hold the probed information in memory but the information remains available on display, then one will also be able to respond quickly, if and only if one knows where to find the information. This shows that a spatial awareness component should also be incorporated in an anaesthetic DSA model. Again, the environment is part of the agent's cognitive system and it is thus ideally demonstrated with SPAM.

We conclude that the response time measure is as important as the SA measure. The anaesthetist must know not only whether and how to act but also when to act—good timing is an essential part of anaesthesia expertise.[36 37] Thus, we are urging researchers, practitioners, and trainers to factor temporal and spatial awareness as integral components of the DSA model, within perception, comprehension, and projection.

The studies described above[27 28] illustrate a limited view by SA researchers.

Emphasis is placed on treating SA as a concept focusing primarily on the monitoring of the patient while ignoring the other elements in the environment to the detriment of the anaesthetists' understanding of their SA.

Six modes of error detection processes have been identified in anaesthesia[38] that promote a DSA approach.

 (i) Standard check: people catch an error through routine monitoring of the environment.
 (ii) Detection on the basis of outcome signs: people catch an error using the effect of the action on the patient.
 (iii) Suspicion from knowledge: people are perplexed and form a hypothesis on the basis of their knowledge.
 (iv) Interpellation: error is not self-detected but detected by someone else.
 (v) Alarm: people catch an error after an alarm.
 (vi) By chance.

As an example for the second process, using the effect of action on the patient, we can take obstetric anaesthesia where the parturient can be awake thanks to epidural or spinal anaesthesia, thus she can communicate vital information before the anaesthetist notices a change in her vital signs such as feeling light headed, nauseated, or in pain.

These modes of error detection processes fit well with a DSA view in anaesthesia as grounded in and emergent from the interaction between anaesthetists (e.g. standard check practice), other people in the team (e.g. interpellation), and external artifacts in the environment (e.g. alarms). Sources of error, and consequently sources of insight, do not exist in monitoring equipment alone. Furthermore, these error detection processes are necessary but not sufficient conditions for ensuring safe anaesthetic practice: the anaesthetist must understand their significance in the context in which they arise and must act accordingly.

We now present a case that occurred in the UK which resulted in a fatality. Many key facts of this case have been presented in public, so we can use this to illustrate some of the more important points of DSA. The case provides an opportunity to demonstrate how SA is embedded and embodied within particular features of the situation and invites practitioners to self-reflect on the human factors that are inherent in the management of every patient.

The Elaine Bromiley case

The death of Elaine Bromiley[39] demonstrates a fixation error during the management of a difficult airway. Fixation occurs when anaesthetists concentrate on a single aspect of the case to the detriment of other more relevant aspects.[40 41] We need to understand how SA is developed and maintained in order to avoid such fixation. We will now consider the Elaine Bromiley case from a DSA perspective.

After induction, the patient's oxygen saturation started to deteriorate when initial attempts at airway management and oxygenation failed. There was a continued deterioration of oxygen saturation, and airway management attempts changed from laryngeal mask airway insertion to intubation. The attempts to intubate the patient were unsuccessful. This had now become a case of 'can't intubate, can't ventilate',[42] yet this remained unrecognized by the anaesthetists and therefore established algorithms for the management of this situation were not considered or followed. The problem was compounded by an apparent loss of awareness of the duration of the period of hypoxia.

Taking a DSA approach, we can better examine the converging factors that contributed to this fixation error and discuss the missed opportunities—beyond just considering patient monitoring as advocated by the traditional SA model—to escape fixation. Throughout most of the case, the patient's oxygen saturation was very low. Although this information was in the monitoring display (perhaps, the audible alarm was also activated), the full importance of this information (the length of time or the extent of the desaturation) did not register quickly enough for successful management. Monitors and alarms only alert anaesthetists to the existence of a problem, but they do not alert them to its solution. Obviously, technology is not a panacea. Other people, in this case, were potentially important but opportunities to escape fixation by making use of their input were also missed.

According to the enquiry report, relatively early (after 6–8 min), one of the nurses recognized the seriousness of the

situation and phoned the intensive care unit (ICU) to reserve a bed for the patient. On informing the consultant anaesthetists, she was 'dismissed' and thereafter cancelled the bed. The senior operating department practitioner also recognized the seriousness of the situation and took action by requesting a tracheotomy kit, but this was ignored. Afterwards, another two members of the team stated that they knew what needed to happen in this situation (i.e. the use of a surgical airway), yet they did not speak up. From a traditional SA perspective, having the focus of analysis on the anaesthetist shows SA as an individual's (in the head) endeavour. Thus, the overall team interactions seem redundant. But from a DSA perspective, the focus of analysis shifts to the distributed cognitive system which includes these interactions, thus making SA an emergent property of the system as a whole. DSA may be associated with the anaesthetist but does not reside within them, instead it emerges from their interactions within the distributed cognitive system. Thus, the DSA approach places an emphasis on the way information knowledge is distributed across people and artifacts rather than on their existence alone. For example, making the tracheotomy kit available as an external artifact (source of information or knowledge) is not enough. It is necessary to communicate its importance successfully rather than just making it visible.

A high degree of cognitive flexibility is required to adapt to an evolving event,[3] such as the case of airway difficulties described above. Anaesthetists need to release previous held beliefs in a flexible manner when the situation does not match their expectations. However, emphasis should be placed on *how* this re-evaluation is achieved through interaction as the DSA model suggests. The Elaine Bromiley case encapsulates the need for better communication between different components of the distributed cognitive system for effective and safe patient management.

Consequences for future research and training

From a DSA point of view, to acquire/have SA is to direct a course of personal interactions with the environment towards a goal. It is from this bidirectional process of searching for information to act and acting to acquire information that good SA emerges. The effectiveness of SA is, therefore, clearly constrained by the level of the anaesthetist's attention to the relevant information (whether monitored physiological variables, progress update between surgeons, or merely embodied manifestations of a change in the situation) and the respective calibration of their actions to that information.

In this paper, we have clarified how SA processes could be better understood as an integral part of goal-directed behaviour that is influenced by the dynamics between anaesthetists and their environment (external artifacts and people). In line with this standpoint, a DSA approach proposes that SA is strongly influenced by the detection and the use of contextual information and the acquisition of SA skill is characterized by the progressive calibration to relevant sources of information at the right time.

Different kinds of activities and different types of information produce various cognitive functions, although all of them have their basis in perceptually guided encounters with the environment. Researchers can actually test hypotheses about both action and cognition directly. Empirical studies should highlight the emergent nature of SA which is dependent on the interaction of each anaesthetist with the specific constraints (external artifacts and other people) of each anaesthesia context. The unit of analysis should be the interaction between the components of the system, not the components themselves.

Despite our criticisms, the empirical studies reported here raise interesting questions and challenge us to think of new related questions. For example, what is the effect of the different monitoring displays on other operating theatre team members' SA? How does that sense of SA in return affect the anaesthetist? For example, in the case of auditory alarms in anaesthetic monitoring displays,[43] the alarm may be an external artifact that acts as a mediator for collaborative work.[44] The vibrotactile display may actually impair team performance as it concentrates solely on the anaesthetist to the exclusion of supporting collaborative work.

As an initial training strategy, establishing what is relevant is essential. Training anaesthetists to go beyond monitoring and incorporate more relevant aspects of each particular case at appropriate times could enlighten their practice. Consequently, establishing when things emerge as relevant and when not is an essential component of expertise. As shown in the Elaine Bromiley case, even though other members of the team realized the severity of the problem and one even provided equipment suggesting a solution, ineffective communication prevented this suggestion being taken up. For example, placing the phone call to reserve a bed in ICU without consulting with the rest of the team in advance and making the situation explicit may have had an effect on the way the suggestion was rejected *post hoc*. Also, making a tracheotomy kit available without explicitly pointing out its value for the particular case at the particular moment may also have influenced how the suggestion was received. Communication skills are not independent of SA: as the information in the displays needs to be better grouped and laid out (see the empirical studies above), communication between the team members also needs to have a better structure that clearly gets to the problem and, subsequently, to its solution.[45–47]

Furthermore, '[t]raining anaesthesiologists to recognize and correct such events is of equal or great importance to attempting to prevent the events in the first place'.[40] Human error is ubiquitous, thus correction is indeed a more realistic strategy than prevention. Perhaps, anaesthetists even fixate on prevention—when an unplanned incident occurs, some may become so wrapped up in their 'failure' to prevent this that they lose perspective on potential success of correcting the incident. Providing and training for corrective protocols would be a better strategy in improving SA, avoid fixation errors, and improve patient safety.

The theoretical analysis of how cognition can be captured in a DSA framework in anaesthesia is in its infancy. However, we argue that DSA provides a powerful new way of thinking about anaesthetic practice. Research is required to identify the interactions within the distributed cognitive system and how these foster or hinder safe anaesthetic practice and how this may apply to training.

Acknowledgement

Conflict of interest

None declared.

Funding

References

1 Endsley MR. Toward a theory of situation awareness in dynamic systems. *Hum Factors* 1995; **37**: 65–84

2 Flach J, Mulder M, van Paassen MM. The concept of the situation in psychology. In: Banbury S, Temblay S, eds. *A Cognitive Approach to Situation Awareness: Theory and Application*. Aldershot: Ashgate, 2004; 42–60

3 Gaba DM, Howard SK, Small SD. Situation awareness in anesthesiology. *Hum Factors* 1995; **37**: 20–31

4 Fletcher G, McGeorge P, Flin R, Glavin R, Maran N. The role of non-technical skills in anaesthesia: a review of current literature. *Br J Anaesth* 2002; **88**: 418–29

5 Fletcher G, Flin R, McGeorge P, Glavin R, Maran N, Patey R. Anaesthetists' Non-Technical Skills (ANTS): evaluation of a behavioural marker system. *Br J Anaesth* 2003; **90**: 580–8

6 Fletcher G, Flin R, McGeorge P, Glavin R, Maran N, Patey R. Rating non-technical skills: developing a behavioural marker system for use in anaesthesia. *Cogn Techn Work* 2004; **6**: 165–71

7 Flin R, Patey R, Glavin RJ, Maran N. Anaesthetists' non-technical skills. *Br J Anaesth* 2010; **105**: 38–44

8 Smith K, Hancock PA. Situation awareness is adaptive, externally directed consciousness. *Hum Factors* 1995; **37**: 137–48

9 Hutchins E. *Cognition in the Wild*. Cambridge, MA: MIT Press, 1995

10 Hazlehurst B, McMullen CK, Gorman PN. Distributed cognition in the heart room: how situation awareness arises from coordinated communications during cardiac surgery. *J Biomed Inform* 2007; **40**: 539–51

11 Hazlehurst B, Gorman PN, McMullen CK. Distributed cognition: an alternative model of cognition for medical informatics. *Int J Med Inform* 2008; **77**: 226–34

12 Patel VL, Kaufman DA, Arocha JF. Emerging paradigms of cognition and medical decision making. *J Biomed Inform* 2002; **35**: 52–75

13 Stanton NA, Stewart R, Harris D *et al*. Distributed situation awareness in dynamic systems: theoretical development and application of an ergonomics methodology. *Ergonomics* 2006; **49**: 1288–311

14 Stanton NA, Salmon PM, Walker GH, Jenkins DP. Is situation awareness all in the mind? *Theor Issues Ergonomics Sci* 2010; **11**: 29–40

15 Rudolph JW, Morrison JB, Carroll JS. The dynamics of action-oriented problem solving: linking interpretation and choice. *Acad Manage Rev* 2009; **34**: 733–56

16 Zhang J. The nature of external representations in problem solving. *Cogn Sci* 1997; **21**: 179–217

17 Zhang J, Norman D. Representations in distributed cognitive tasks. *Cogn Sci* 1994; **18**: 87–122

18 Drews FA, Westenskow DR. The right picture is worth a thousand numbers: data displays in anaesthesia. *Hum Factors* 2006; **48**: 59–71

19 Wright MC, Taekman JM, Endsley MR. Objective measures of situation awareness in a simulated medical environment. *Qual Saf Health Care* 2004; **13**: i65–i71

20 Sorkin RD, Woods DD. Systems with human monitors: a signal detection analysis. *Hum-Comput Interact* 1985; **1**: 49–75

21 Klemola U-M, Norros L. Practice-based criteria for assessment the anaesthetists' habits of action: outline for a reflexive turn in practice. *Med Educ* 2001; **35**: 455–64

22 McIlvaine WB. Situation awareness in the operating room: a primer for the anaesthetist. *Semin Anaesth Periop Med Pain* 2007; **26**: 167–72

23 Noë A. *Action in Perception*. Cambridge, MA: MIT Press, 2004

24 Norros L, Klemola M. Naturalistic analysis of anaesthetists' clinical practice. In: Montgomery H, Lipshitz R, Brehmer B, eds. *How Experts Make Decisions*. Hillsdale, NJ: Lawrence Erlbaum, 2005; 395–407

25 Klein GA. A recognition-primed decision (RPD) model of rapid decision making. In: Klein GA, Orasanu J, Calderwood R, Zsambok CE, eds. *Decision Making in Action: Models and Methods*. Norwood, NJ: Ablex, 1993; 138–47

26 Baber C. Wearable technology for crime scene examination: distributed cognition and naturalistic decision making. *Proceedings of the 9th International Conference on Naturalistic Decision Making*, London, UK, June 23–26, 2009

27 Ford S, Daniels J, Lim J *et al.* A novel vibrotactile display to improve the performance of anaesthetists in a simulated critical incident. *Anesth Analg* 2008; **106**: 1182–8

28 Zhang Y, Drews FA, Westenskow DR *et al.* Effects of integrated graphical displays on situation awareness in anaesthesiology. *Cogn Tech Work* 2002; **4**: 82–90

29 Endsley MR. Direct measurement of situation awareness: validity and use of SAGAT. In: Endsley MR, Garland DJ, eds. *Situation Awareness Analysis and Measurement*. Mahwah, NJ: Lawrence Erlbaum, 2000; 147–73

30 Blike GT, Surgenor SD, Whalen K. A graphical object display improves anesthesiologists' performance on a simulated diagnostic task. *J Clin Monit* 1999; **5**: 37–44

31 Durso FT, Dattel AR. SPAM: the real-time assessment of SA. In: Banbury S, Temblay S, eds. *A Cognitive Approach to Situation Awareness: Theory and Application*. Aldershot: Ashgate, 2004; 137–54

32 Clark A, Chalmers D. The extended mind. *Analysis* 1998; **58**: 7–19

33 Pritchett AR, Hansman RJ, Johnson EN. Use of testable responses for performance-based measurement of situation awareness. In: Garland DJ, Endsley MR, eds. *Experimental Analysis and Measurement of Situation Awareness*. Daytona Beach, FL: Embry-Riddle Aeronautical University Press, 1995; 75–81

34 Sarter NB, Woods DD. How in the world did I ever get into that mode? Mode error and awareness in supervisory control. *Hum Factors* 1995; **37**: 5–19

35 Selcon SJ, Taylor RM, Koritsas E. Workload or situational awareness?: TLX vs SART for aerospace systems design evaluation. *Proceedings of the Human Factors Society 35th Annual Meeting*. Santa Monica, CA, 1991; 62–6

36 Nyssen A, Javaux D. Analysis of synchronization constraints and associated errors in collective work environments. *Ergonomics* 1996; **39**: 1249–64

37 Sougné J, Nyssen AS, De Keyser V. Temporal reasoning and reasoning theories: a case study in anaesthesiology. *Psychol Belg* 1993; **33**: 311–28

38 Nyssen A, Blavier A. Error detection: a study in anaesthesia. *Ergonomics* 2006; **49**: 517–25

39 Bromiley M. Have you ever made a mistake? *R Coll Anaesth Bull* 2008; **48**: 2442–5

40 DeAnda A, Gaba DM. Unplanned incidents during comprehensive anaesthesia simulation. *Anesth Analg* 1990; **71**: 77–82

41 Fioratou E, Flin R, Glavin R. No simple fix for fixation errors: cognitive processes and their clinical applications. *Anaesthesia* 2010; **65**: 61–9

42 Henderson JJ, Popat MT, Latto IP, Pearce AC. Difficult airway society guidelines for management of the unanticipated difficult intubation. *Anaesthesia* 2004; **59**: 675–94

43 Sanderson P. The multimodal world of medical monitoring displays. *Appl Ergon* 2006; **37**: 501–12

44 Xiao Y. Artifacts and collaborative work in healthcare: methodological, theoretical, and technological implications of the tangible. *J Biomed Inform* 2005; **38**: 26–33

45 Garbis C, Arman H. Team situation awareness as communicative practices. In: Banbury S, Temblay S, eds. *A Cognitive Approach to Situation Awareness: Theory and Application*. Aldershot: Ashgate, 2004; 275–96

46 Hindmarsh J, Pilnick A. The tacit order of teamwork: collaboration and embodied conduct in anesthesia. *Sociol Quart* 2002; **43**: 139–64

47 Hindmarsh J, Pilnick A. Knowing bodies at work: embodiment and ephemeral teamwork in anaesthesia. *Organ Stud* 2007; **28**: 1395–416