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Situation Awareness – Bridging Neuroscientific and Human Factors/ Ergonomics Perspectives and Implications for Clinical Practice

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ABSTRACT

A key challenge for clinicians is to make sufficient sense of what is happening around them to anticipate what might happen next and take timely action. This review article examines the theoretical basis of Situation Awareness (SA) - defined by Endsley 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" (SA Levels I, II and III respectively) – and its relevance to clinical practice. SA is fundamental to good decision-making, and in turn to safe and effective human performance. Traditional models of clinical history taking / examination / investigation / diagnosis / prognosis align with the basic components of SA and can be further refined when viewed through the prism of SA, and its scope further extended by incorporating psychological, neurocognitive and statistical (Bayesian) perspectives.

Stress, fatigue and environmental noise/distractions can significantly impair SA, while other factors can significantly improve it. Experts experience a different perceptual world to novices, and techniques that may accelerate the acquisition of expert clinical SA (e.g. deliberate reflection, simulation, ergonomic environmental design etc.) could be beneficial to clinical practice. Moreover one can distinguish individual SA from 'shared' and 'team' SA, where specific communication, teamworking and leadership skills become relevant. Clinical emergencies and crises usually entail greater urgency, ambiguity, volatility and uncertainty, and impose a greater challenge on clinicians to form adequate SA in real time. Examples of SA in everyday clinical practice and the extent to which SA can be improved by adapting the clinician (through training) and/or adapting the work environment (through workplace/organisational design) are discussed.

Keywords: Situation Awareness, Neuroscience, Cognition, Human Factors, Ergonomics, Medical Education, Patient Safety

Introduction and Rationale

A key challenge for clinicians is to make sufficient sense of what is happening around them to anticipate what might happen next and take timely action, and for clinical teams similarly to function under a shared mental model. Situation awareness (SA) is an important human factors/ergonomics (HF/E) concept which arguably underpins all other non-technical skills such as perception of risk, communication, teamwork, leadership and managing automation.

This review article seeks to define SA and examine its counter-intuitively plastic and dynamic nature from several perspectives, in order to show the links between our current neuroscientific understanding of how the brain processes information and the practical aspects of the applied cognitive psychology underpinning the concept. The article will then explore more directly how SA relates to clinical practice, the factors that affect SA in healthcare environments, the differences between novice and expert SA, the extended concepts of team, shared and distributed SA, and finally the implications of SA for medical education and the design of healthcare systems more generally. Examples will be taken from anaesthetics and critical care (the author's field of clinical expertise) however the concepts can in principle be readily extrapolated to other healthcare domains.

Definition of Situation Awareness

The roots of SA can be found in classical writings of military strategists such as Sun-Tzu ('know your enemy")[1] and von Clausewitz ('knowledge of circumstances')[2], emphasising recurrent themes of gathering intelligence and understanding/anticipating your opponent. Endsley defined SA formally 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*".[3,4] SA can be deconstructed into three levels: Perception, Comprehension and Projection.

Level I Situation Awareness – Perception

The first level of SA relates to perception of the status, attributes and dynamics of elements in an environment. It corresponds to the traditional framework of clinical assessment – reviewing a patient's chart, taking a history, examining the patient, observing monitors, ordering investigations, consulting/conferring with colleagues etc. The ability to ask the right questions, to examine methodically and to navigate electronic medical record systems are all learned skills. Even when proficiency is gained, other factors can impair the ability to perceive key elements of a clinical situation (see below).

Level II Situation Awareness – Comprehension

Level II corresponds to the forming of a mental model that makes sense of clinical findings – a clinical impression, a working diagnosis plus differential etc. History and examination often suggest a range of likely conditions; there may be atypical presentations of less likely conditions. The ability to assign differential weight to a range of possible diagnoses and to adapt in the light of new information is learned over time through conscious reflection of aggregated experiences. Understanding how a range of contextual and environmental factors (clinical urgency, remote location, limited resources, operating in the middle of the night, interpersonal conflict etc.) can impact on human performance is part of Level II SA.

Level III Situation Awareness – Projection

The "brass ring" of SA is the ability to use one's clinical understanding of a situation to predict what will happen in the future and to act on that prognosis in a timely manner - not only to manage complications, but ideally to prevent them from happening. Pilots are taught to make sure 'the brain is always five minutes ahead of the plane'; anaesthetists are taught to 'think five minutes ahead of the vapour'. Examples of effective Level III SA strategies in clinical practice include the "Between The Flags" system of vital signs monitoring to alert staff to trends of patient deterioration[5] and the evolution of Cardiac Arrest Teams to Medical Emergency Teams (MET), designed nowadays to manage not only arrested patients, but also deteriorating patients pre-arrest, thereby reducing overall mortality.[6]

The Dynamics of Situation Awareness

The serial logic underpinning this model (perception →comprehension→prediction) is intuitively appealing but serves only as the foundation of a network of more complex cognitive processes as observed in the real world (see Fig. 1). The next few paragraphs take a deeper dive into the neural basis of cognition seeking further insight into how SA is generated and maintained.

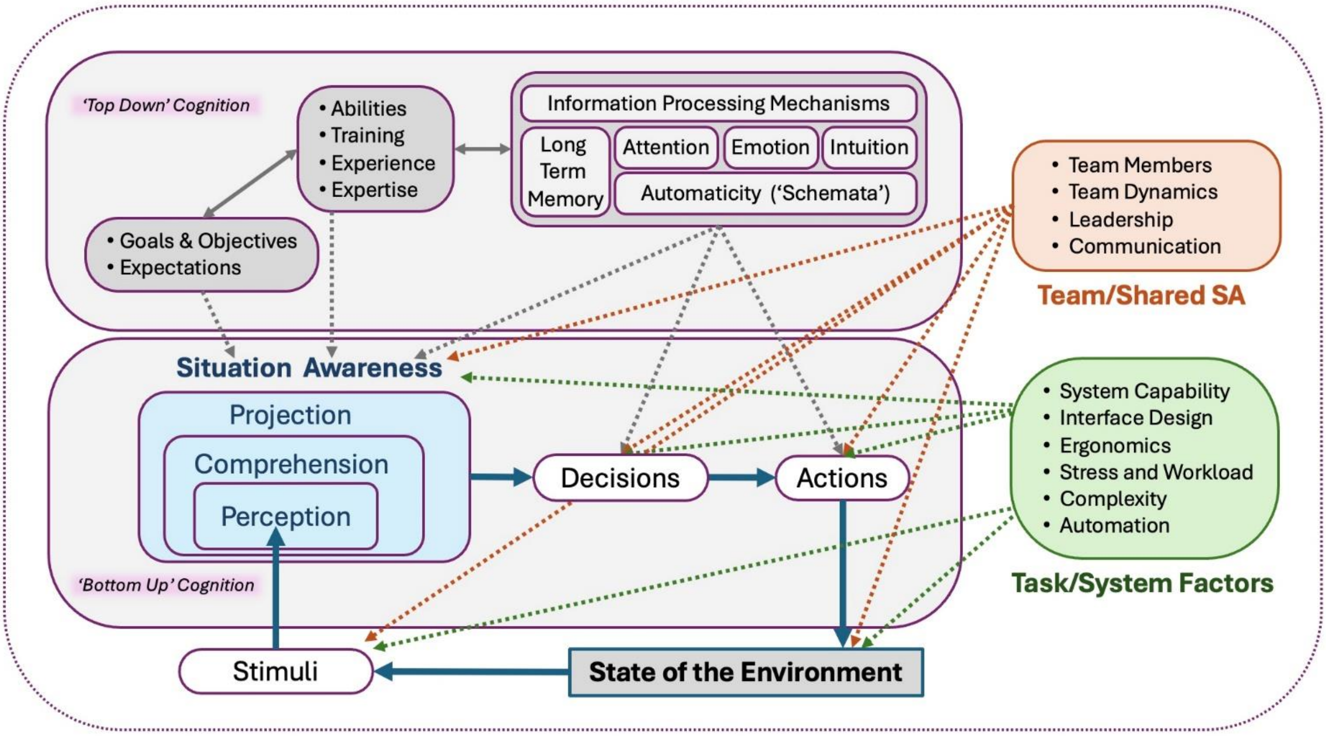

Fig 1. A Situation Awareness Model. Adapted from Endsley[4]

SYNAPTIC PLASTICITY

Information in biological brains is not held in binary digital packets the way it is stored in computers. Humans are born with a rudimentary 'firmware' of neuroanatomical connections but the ability to process, retain and recall information relies upon activation dependent synaptic plasticity (ADSP)[7] occurring not just in infancy but throughout our lifetime. New experiences result in firing of neurons along a myriad of pathways; repeated stimulation along the same pathway within a critical timeframe results in an increase in the number of synaptic connections between activated neurons as well as a lowering of the neurotransmitter threshold for future stimulation. These make it more likely that subsequent stimulation will trigger the same pattern of firing. This biasing or *synaptic weighting* is fundamental to Hebbian learning, colloquially summarised as 'neurons that fire together wire together'[8].

Synaptic plasticity is how the brain codes information about the world. Studies of taxi drivers demonstrated that subjects trained in 'The Knowledge' of navigating London streets over a period of years acquired significantly larger posterior hippocampi than controls, postulated to be as a direct result of ADSP.[9] This plasticity occurs not only in the hippocampus but wherever multipolar interneurons connect and interact throughout the brain; so most of the experiential 'biasing' of processed information about the world that the brain retains occurs beneath the level of consciousness. Synaptic weighting is happening all the time, even while we sleep.[10] Thus the organ we use to experience and understand the world is constantly, often imperceptibly changing: to paraphrase Heraclitus, "No person can enter the same river twice, for it is not the same river *and they are not the same person*".[11]

MENTAL MODELS AND SCHEMATA

The challenge for any brain is to discern meaning from the chaos of information about the self and the world around it in real time with only the limited processing power at its disposal. Through natural selection it appears that early neural networks acquired the ability to filter and 'chunk' aggregate neural activity into crude summary packets of that activity. These mental 'models' – precursors of 'meaning' - are refined by the hierarchical winnowing of information through intense competition between activated neural pathways in the midbrain, limbic system, hypothalamus, thalamus and ultimately the cerebral cortex.

The statistician George Box made the famous observation that "all models are wrong, but some are useful".[12] All the models created by the brain are 'wrong' is so far as they are at best rough approximations; however many prove useful through the outcomes they produce. Useful models are retained, refined and become *schemata*,[13] repertoires of thinking patterns and behaviour that run in the background or are activated by specific triggers. Collectively these subconscious 'best guesses' can be thought of as the brain's 'autopilot', traditionally assigned to the basal ganglia but, like most higher order cognitive functions, now thought to be distributed across a much wider "default mode network" of brain structures.[14]

The increasing sophistication of information processing and modelling by central nervous systems can be tracked across species through key evolutionary steps from early metazoans to modern-day humans over hundreds of millions of years:[15,16] from the ability to focus attention by enhancing certain neural inputs while inhibiting others, to learning through physical trial and error (pavlovian conditioning), to the ability to imagine future states, abstracted learning through *imagined* trial and error (counterfactual or 'what if' learning), to modelling one's own state of attention and that of others,[17] and ultimately to the rich, 'meaningful' subjective experience that is human consciousness.

THE BAYESIAN BRAIN

In the traditional SA model, clinicians learn to evaluate complex clinical information from a range of sources (Level I SA) to arrive at probable diagnoses (Level II SA) and prognoses (Level III SA). This can be seen as a 'bottom-up' approach to cognitive processing - sensory inputs drive initial conscious perceptions, which are serially processed by higher cognitive centres. However, a wealth of research on various optical, sensory and cognitive illusions[18,19,20,21] suggests that there is much more to how the brain forms conscious perceptions.

In the 'Bayesian Brain Hypothesis' (BBH)[22,23] the brain is treated as 'statistical inference engine'[24] which is constantly and unconsciously trying to predict future states on the basis of past experience. Clinicians are most familiar with Bayesian theory when evaluating medical investigations and their predictive value based on specificity, sensitivity, false positives and negatives etc.[25] The effect of prior knowledge on probabilistic predictive power is often counterintuitive, shown most elegantly by the 'Monte Hall Problem'[26] and other cognitive paradoxes. BBH is often described as a 'top-down' theory of cognition – our conscious perceptions of the world are to a large extent shaped by context and prior knowledge. The eyes are more than mere cameras; they 'see' what brain *predicts* they should see, calibrated as needed by salient sensory inputs (e.g. see Fig. 2).

Fig.2. The Cat Sat On The Mat Illusion. Readers prompted by the picture will on first impression tend to see the text as "The Cat Sat On The Mat" despite the 'A's and the 'H's being the same ambiguous character. It then takes conscious effort to 'unsee' it. Where signals are vague or unclear, context often drives perception.

BBH has implications for more traditional models for SA predicated on 'bottom-up' cognitive processes. 'Top-down' elements better explain how with time and reflected experience, the serial hierarchy of perception-comprehension-projection becomes less distinct; prior diagnoses and prognoses shape future perceptions and perceived likelihoods, and the three levels of SA tend to coalesce into a single gestalt which form the basis of expert SA (see below).

SYNTHESIS

In summary, several relevant threads emerge. First, our picture of the world is built and maintained through patterns of synaptic weights reinforced by prior experiences which bias information processing from the perceptual level upwards. Second, parts of the brain are constantly competing with each other – some win, some lose (often for reasons not consciously apparent to us) but they all nevertheless effect plastic changes across the brain whenever they are active, even when we sleep. Third, what we understand as 'consciousness' represents only a fraction of the massive amount of biased information about the world that the brain has already stored and continues to process throughout our lifetime. Next, the models formed by the brain are fundamentally crude 'executive summaries' of complex neuronal activity whose sophistication and utility in humans are the culmination of millions of years of evolution. Finally, our sense of reality in any given moment lies somewhere between perception, memory and prediction: consciousness is not just driven from the 'bottom up' by our senses but also from the 'top-down' by our subconscious 'schemata' and 'autopilot'. The world we 'see' is framed by an often arcane mix of what we have seen before and what we hope to see, as the Bayesian brain's 'best guess' of reality. All of these elements have implications for how SA is elaborated and susceptible to a range of biological and non-biological factors.

Inattenional Blindness and Manipulating Perceptions

Under certain circumstances our senses do not render faithfully what is in front of us. Entertaining examples of 'inattentional blindness' are Simons and Chabris' notorious 'Basketball' Video[27,28] and Wiseman's 'Amazing Colour Changing Card Trick'.[29] These videos illustrate how perception itself can be altered and indeed misdirected by distractions or other cognitive activities such as focusing intently on a task. Medical hypnosis, a technique which allows a patient's past memories of joyful or pleasant sensations to be experienced vividly as if they were in the present, has been shown to relieve anxiety and pain in a range of invasive procedures under local anaesthetic;[30,31,32] this is not only evidence of the manipulability of SA, but also an indicator of the practical benefits of understanding the plastic nature of SA in clinical environments.

Novice vs Expert Situation Awareness

Abundant research into Naturalisitic or Recognition Primed Decision Making (NDM or RPDM) has demonstrated that highly attuned SA is fundamental to how experts make decisions.[33,34] Novices and experts, looking at exactly the same clinical situation, have very different perceptual and cognitive experiences. The novice may ask fifty system review questions and examine a patient thoroughly, gathering a wealth of clinical information, but struggle to integrate them into a diagnosis. The expert will also interrogate and examine the patient diligently, but having 'eyeballed' the patient will have already made a (usually correct) working diagnosis and management plan based on only a few targeted questions and signs specifically sought on examination. This is due to the large bank of iterative and reflected experiences influencing synaptic weighting and 'Bayesian Brain' logic, prefacing what they see and look for. Cues in the immediate environment trigger simultaneous intuitive perceptions, comprehensions and projections. All three levels of SA merge into a single gestalt, in what Klein describes as 'seeing the past, present and future as one'.[35] This principle lies at the heart of RPDM. Experts have an enhanced faculty to simulate mentally the outcomes of potential courses of action i.e. they have more highly developed Level III SA. Beyond a certain point experts exhibit tacit knowledge in their area of expertise – they may find it difficult to articulate how or why they know what they know – also known as 'unconscious competence'.[36]

Experts are more adept at modifying their mental models in the light of new information and are more sensitive to context and changes in detail.[37] Trainees are frequently taught 'if you hear hooves, it's a horse, not a zebra' - an entirely appropriate heuristic in many situations; a person with expert SA is more likely to think 'if you hear hooves, it's a horse… unless you're in the Serengeti, then it probably *is* a zebra'.

Experts are often more attuned to their own emotions, intuitions and 'gut-feelings' (reflecting subconscious information processing) such as unease or discomfort, which trigger further conscious enquiry and information gathering. Surgeons frequently refer to their comfort level when deciding on whether or not to proceed with laparoscopic procedures.[38]

The '10000-hour rule' for acquiring expertise popularised by Gladwell[39] based on the work of Eriksson[40] has gained attention in the medical education literature, but there has been a growing counter-commentary reminding readers that clocking hours of experience alone is not enough;[41,42] rather it is the quality of reflection on those hours of experience ('*deliberate practice*') that better determines the level of expertise,[43,44] a point made in the original literature but often missed.[45]

Inadequate Situation Awareness

In adverse event analysis reports it is common to read of practitioners 'losing situation awareness' leading to an incident. However, as Flach has asserted, "SA exists only in the mind of the researcher, not as an object in the mind being studied".[46] Unless consciousness itself is impaired or lost, SA is not something that can be 'lost'; rather it is a dynamic state of mind that is always active but may or may not be appropriate/adequate for the requirements of the task at hand. Endsley proposed a simple taxonomy of SA errors based on the three levels (see Table 1).[47] Schulz et al. used this classification to analyse 200 anaesthetic and critical care adverse events and found SA errors in 81.5% of cases, the majority of errors being related to failures of perception and comprehension.[48]

Table 1. A Taxonomy of SA Errors with clinical examples. Adapted from Endsley[40]

Error Category		Examples of Clinical Sources of SA Error
Inadequate Level I SA – Failure to Perceive/Misperception of Information		
1.1	Data was not available	No/misplaced medical records Unable to take a history (comatose pt/unable to communicate) Unable to examine (tele-consults/belligerent pt) Test results not available
1.2	Data was hard to discriminate or detect	Noisy/busy/chaotic environments Conflicting/contradictory information Low signal-to-noise ratio problems Non-specific/atypical clinical findings Underdeveloped clinical acumen Internal performance shaping factors
1.3	Failure to monitor/observe data	Not taking a history/examining patient/reading the notes Not ordering diagnostically useful tests Not monitoring/following up Not conferring/consulting/asking for help Failure to perceive the passage of time Clinical task saturation/overload/distractions Internal performance shaping factors
1.4	Misperception of data	Underdeveloped clinical acumen Deteriorating practitioner senses (poor eyesight/hearing) Poor resolution/margin of error of investigative tests Internal performance shaping factors
1.5	Memory loss	Clinical task saturation/overload/distractions Ageing practitioners Internal performance shaping factors
Inadequate Level II SA – Improper integration/Comprehension of Information		
2.1	Lack of/incomplete mental model	Inability to form a clinical impression Internal performance shaping factors
2.2	Use of an incorrect mental model	Misdiagnosis Gaba's Triad of Fixation Errors Internal performance shaping factors
2.3	Over-reliance of default values	Anchoring bias Adopting 'second-hand' diagnosis without conducting one's own assessment Assuming/guessing vs checking/verifying Internal performance shaping factors
Inadequate Level III SA – Incorrect Projections of Future Trends		
3.1	Lack of/incomplete mental model	Failure/inability to make a prognosis Failure to recognise an acutely deteriorating patient Underdeveloped clinical acumen Internal performance shaping factors
3.2	Over-projection of current trends	Overdosing/overtreatment Underdosing/undertreatment ('She'll be right')

The adequacy of clinical SA needs to be actively monitored, maintained and calibrated in real time, not just because clinical situations often change rapidly, but also because human cognition itself is vulnerable to range of performance shaping factors (PSFs). These are summarised in Reason's 'Three Buckets' (see Fig 3).[49] For example, fatigue and sleep deprivation (e.g. in night shift work) are known to significantly impair cognition and clinical decision-making[50,51] while stress is recognised as a major PSF that impairs diagnostic accuracy, reaction time, attention and memory, leading to poorer safety outcomes such as medication errors and hospital acquired infections.[52] Distractions are a significant cause of impaired cognitive clinical performance.[53] Disorientation and lack of familiarity with the work environment is a significant PSF for new employees[54] and locum doctors/agency nurses.[55] PSFs apply to experts and novices alike. Practitioners are advised to 'HALT' (i.e. pause and reflect/confer) if they are 'Hungry Angry Late or Tired'.[56] In susceptible mental states, where signals are vague or ambiguous the balance of perception is more likely to be tipped toward subconscious schemata than sensory inputs, and practitioners are more likely to 'see' a memory of what had been seen, or what they projected they would see, rather than what is actually there, clouding subsequent SA.

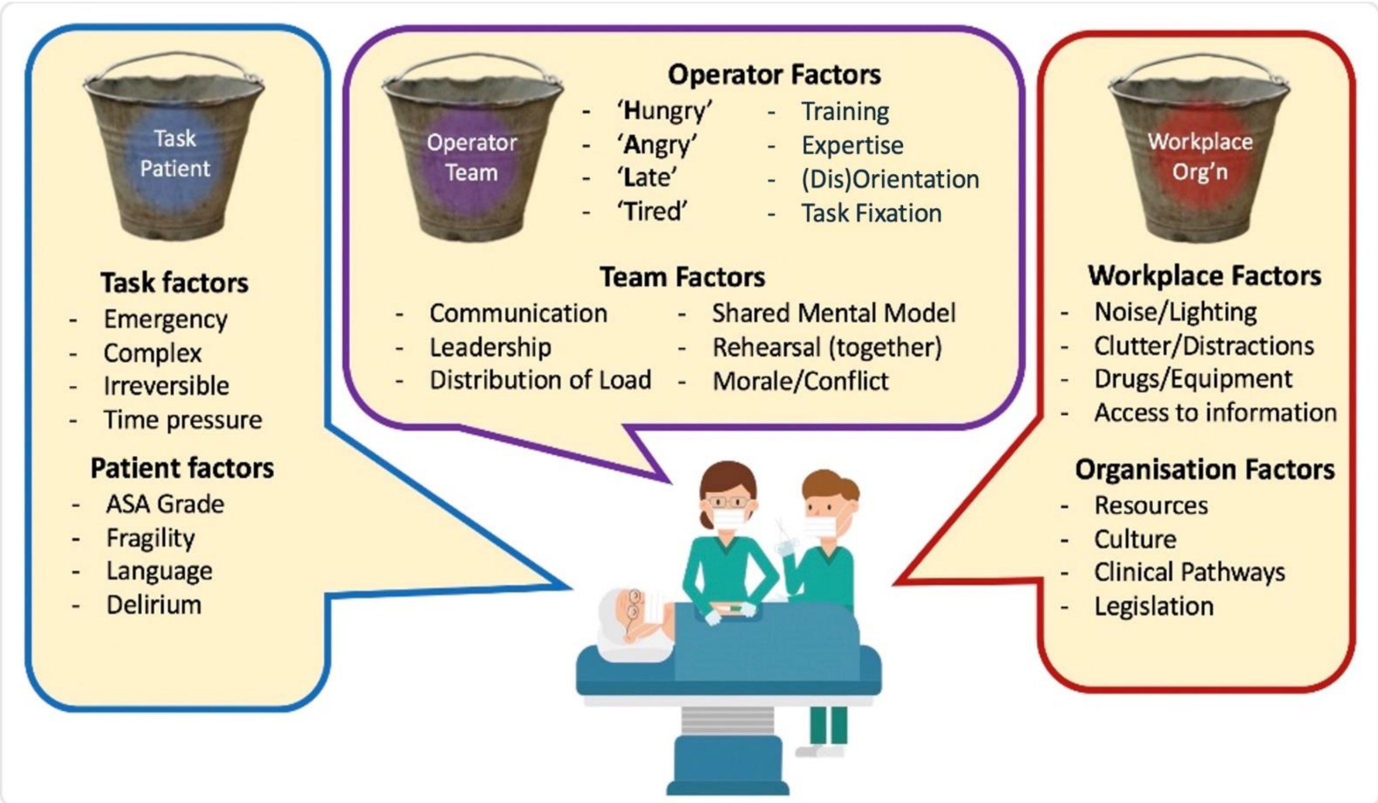

Fig 3. Performance Shaping Factors – Reason's 'Three Buckets'.

Gaba's triad of fixation errors[57,58] rates a special mention in the context of deteriorating patients not responding to resuscitation efforts. The triad refers to cognitive behaviours commonly observed during simulated medical crises: "This And Only This" refers to the tendency to fixate on a particular diagnosis and a refusal to entertain any other differential diagnosis; "Anything But This" is a fixation of exclusion; the practitioner is convinced a particular diagnosis cannot be the cause of ongoing deterioration; "Everything's Fine" is a state of abject denial, a refusal to acknowledge the patient is deteriorating. All three conditions reflect a relative inability under stress to review one's mental model in the light of existing and/or new information. A healthy state of shared SA can help 'reboot' individual team members out of fixation states and help them achieve adequate Level II/III SA.

Failure to perceive the passage of time while focused on a critical technical task (e.g. attempting to intubate) can have disastrous results.[59] Time perception is highly subjective and affected by a surprising range of factors beyond task-focus and distractions, including state of emotional arousal and how fast things are changing in the background,[60] factors common in many clinical emergencies. Untrained humans are generally poor at judging timeframes of exponential/non-linear processes[61], a feature often seen in trauma resuscitations[62] and in deteriorating patients more generally.

An emerging problem in highly automated systems is the 'Out-Of-The-Loop performance problem',[63] where of much of the clinical information processing underpinning adequate SA resides more in automated devices than in the operator. This problem was first noticed in aviation[64] but will manifest itself increasingly in health care settings as the preponderance of intelligent monitors, smart pumps, multimodal ventilators and AI-driven medical equipment grows.[65]

Team and Shared Situation Awareness

The next dimension of complexity arises when teams perform. The individual SAs of each team member related to a given task will be different but must somehow be brought into functional concordance, i.e. they must get 'on the same page'.

A distinction is made between *team* SA (the task-specific SA required of each member in the complex execution of a team task e.g. their particular skills, roles and responsibilities, when each must play their part etc.) and *shared* SA (knowledge and mental models that must be made common to all members of the team to ensure coordinated team performance – e.g. correctly identifying the patient, agreed procedure to be performed, level of urgency etc.)[66] Both elements have been identified as essential to effective team performance.[67] In both team and shared SA, two broad HF/E elements become critical: communication (briefings, handovers, controlled vocabulary, assertiveness, debriefing) and leadership (creating psychological safety, framing the mission, facilitating a shared mental model distributing workload, managing conflict).

Situational leadership (knowing when to be instructive/autocratic vs facilitatory/consultative)[68] utilises Level I Team SA to clarify and adapt to the available skills and knowledge within the team; 'Lighthouse leadership' (where the MET team leader is clinically 'hands-off' to oversee and direct team activity)[69] aims to enhance Level II and Level III Shared SA by affording the leader the cognitive freedom to see and articulate to the rest of the team the bigger picture of what is happening and where things are heading.

Weller et al.[70] identified team/shared SA as a critical component of patient safety and proposed three key improvement measures: building respectful relationships within teams to promote an atmosphere of psychological safety, allowing even junior members to raise and escalate concerns; clear, concise communication strategies to improve shared SA; and development of AI-guided monitor displays that integrate disparate sources of information and offer trend projections of the state of a patient.

Distributed Situation Awareness and Ergonomics

Fioratou et al. proposed an evolution of the traditional SA model applied to anaesthesia called distributed situation awareness (DSA) where knowledge and meaning about the world is seen to reside not just in the minds of the individual human agents but also in the operating theatre environment itself, and in the interplay between the environment and the human agents[71]. The patient, their physiology, the monitors, the surgical field, drugs and equipment, the clock, all the clinicians etc. are in interactive flux, each with information competing for our attention and our cognitive modelling faculties. DSA emerges from appreciating, understanding and anticipating these interactions in real time.

DSA is more consistent not only with our current understanding of how the brain models the world and the Bayesian factors that influence the fidelity of predicting of future states and outcomes, but with a sociotechnical HF/E model of system performance.[72] DSA is as much 'in the world' as it is 'of the world'; to this extent appropriate ergonomic design of equipment and theatre environments can significantly improve SA. For example, the wider adoption of video technology in operating theatres[73] can enhance SA at several levels: live video displays of the operative site and the anaesthetic monitor gives ready and accessible information about the state of the patient and surgical progress to all members of the theatre team throughout the procedure, enhancing shared Level I SA; recording and playback of surgical procedures allows structured and deliberate reflection of skills and decisions, facilitating the acquisition of expert SA; the ability to teleconference operations live with senior specialist colleagues in remote sites permits access to their expert SA; finally the burgeoning use of artificial intelligence in clinical environments promises to create tools that support Level II and Level III SA.

The value of ergonomist input into healthcare workplace design[73,74] and medical equipment design[75] remains largely under-recognised by clinicians and health care executives. The UK Chartered Institute for Human Factors and Ergonomics recently published a guide on integrating human-centred AI for clinical practice which included recommendations for improving individual and team SA.[76]

At a more low-tech level, individual practitioners can modify their immediate work environment to facilitate SA. For example, anaesthetists routinely use syringes with colour-coded labels to readily distinguish medications; they can also arrange their workspace so that the patient, anaesthetic machine, monitoring displays, surgeon, drip stand, pumps, ventilator etc. are all within a single field of view to rapidly detect and assimilate changes in real time. Simple principles of 'personal ergonomics' to improve SA can easily be extrapolated to other clinical arenas.

Training Implications

Understanding SA levels and the factors that affect SA serves as a useful theoretical starting point for developing expert individual and team SA. Having said this true expert SA cannot *per se* be taught; it can only be cultivated over time and through deliberate iterative reflection on practice of every clinical exposure, linking perceptions to mental models to decisions, and ultimately to the outcomes of those decisions.

Good communication is critical to both individual and team SA. Organisational training in structured briefings[77] and handovers using formalised tools such as SBAR/ISBAR[78] should be standard in any clinical team setting. Structured debriefing along SA levels ("What did you see/hear - What did you think was happening - What did you think was going to happen") in both simulated and real-world environments facilitates the acquisition of expert SA in both individuals and teams over time.[79] Training practitioners in situational leadership skills may help adapt team/shared SA to different clinical situations.

High-fidelity simulation offers a safe environment where practitioners and teams to experience and reflect on their cognitive performance in simulated scenarios, thereby shaping SA and modifying future thinking and behaviour.[80] Simulation also offers a more objective assessment of SA through the SA Global Assessment Technique (SAGAT),[81] an established and widely used tool where representative tasks are simulated and scenarios are frozen at randomly selected times, allowing participants to answer brief questions about their current perceptions of the situation. SAGAT has been used to evaluate SA in a range of healthcare teams[82,83,84] and guide training.[85]

A novel low-tech technique for enhancing level I SA is to place clinicians a simulated nightmare clinical environment where participants are asked to identify as many safety-critical errors as possible in a limited time period. Variants of this technique include the "Room of Horrors"[86] and the Patient Safety Escape Room.[87]

Orientation programmes for new graduates, employees and locum/agency staff are now standard practice in most public hospital environments. More work is required to identify the optimum period and content for orientation.

Conclusion

Situation awareness is fundamental to competent clinical decision making and clinical performance of individual practitioners and healthcare teams. Individual SA is the product of a complex interplay between events in the physical environment and competing modelling processes in the brain and is susceptible to a range of performance shaping factors. Expert SA is a skill that can be acquired over time through active reflection of past experiences, and can be accelerated through targeted training, especially medical simulation. Health authorities should seek formal input from professional ergonomists to develop work environments and equipment that can optimise individual and team/shared SA in a range of routine and emergency clinical settings.

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References:

1. Tzu S. *The Art of War.* Giles L Translation of 5th Century BCE manuscript. Available at https://dn790006.ca.archive.org/0/items/TheArtOfWarBySunTzu/ArtOfWar.pdf 2004; 4:18

2. Von Clausewitz C. *Vom Kriege (On War).* Graham JJ Translation of 1874 Edition. Project Gutenberg. Available at https://www.gutenberg.org/files/1946/1946-h/1946-h.htm retrieved 20 March 2025

3. Endsley MR. Design and evaluation for situation awareness enhancement. In *Proceedings of the Human Factors Society 32nd Meeting.* Santa Monica, CA: Human Factors Society. 1988; 97-101.

4. Endsley MR. Situation Awareness. In *Handbook of Human Factors and Ergonomics* (5th Ed.) Salvendy G, Karwowski W. Eds. 2021; Available at https://onlinelibrary.wiley.com/doi/10.1002/9781119636113.ch17.

5. Hughes C, Pain C, Braithwaite J, Hillman K. 'Between the flags': implementing a rapid response system at scale. *BMJ Qual Saf* 2013; 23(9): 714-7. doi: 10.1136/bmjqs-2014-002845

6. Tobin AE, Santamaria JD. Medical emergency teams are associated with reduced mortality across a major metropolitan health network after two years service: a retrospective study using government administrative data. *Crit Care* 2012; 16: R210. doi:10.1186/cc11843

7. Ganguly K, Poo M. Activity Dependent Neural Plasticity from Bench to Bedside. *Neuron* 2013;80: 729-41

8. Agilari E, Aquaro M, Barra A, Fachechi A, Marullo C. From Pavlov Conditioning to Hebbian Learning. *Neural Comput* 2023; 35(5): 930-57. doi: 10.1162/neco_a_01578

9. Maguire EA, Spiers HJ, Good CD, Hartley T, Frackwiak RS, Burgess N. Navigation expertise and the human hippocampus: a structural brain imaging study. *Hippocampus* 2003; 13(2): 250-9. doi: 10.1002/hipo.10087

10. Wang G, Grone B, Colas D, Applebaum L, Mourrain P. Synaptic plasticity in sleep: learning homeostasis and disease. *Trends Neurosci* 2011; 34(9): 452-463. Doi:10/1016/j.tins.2011.07.005

11. Heraclitus. Fragment DK B91. Hoyt R Ed. The Fragments of Heraclitus. Available at https://heraclitusfragments.com/B91/index.html retrieved 20 Mar 2025

12. Box G. Science and Statistics. *J Am Stat Ass* 1976; 71(356): 791-799

13. Ghosh VE, Gilboa, A. What is a memory schema? A historical perspective on current neuroscience literature. *Neuropsychologia* 2014 53: 104-14. doi: 10.1016/j.neuropsychologia.2013.11.010

14. Vatansever D, Menon DK, Emmanuel A. Stamatakis EA. Default mode contributions to automated information processing. *Proc Nat Acad Sci* 2017; 114 (48): 12821-12826. doi: 10.1073/pnas.1710521114

15. Cisek P. Resynthesizing behavior through phylogenetic refinement. *Attent Percept Psychophys.* 2019; 81: 2265–2287. doi: 10.3758/s13414-019-01760-1

16. Bennett MS. What Behavioral Abilities Emerged at Key Milestones in Human Brain Evolution? 13 Hypotheses on the 600-Million-Year Phylogenetic History of Human Intelligence. *Front Psychol* 2021; 12:685853. doi: 10.3389/fpsyg.2021.685853

17. Graciano MSA. *Rethinking Consciousness – A Scientific Theory of Subjective Experience.* WW Norton Pubs. 2019

18. Loeb GE, Fishel JA. Bayesian Action & Perception: Representing the World in the Brain. Front Neurosci. 2014; 8. doi:10.3389/fnins.2014.00341

19. Nour MM, Nour JM. Perception, Illusions and Bayesian Inference. *Psychopathology* 2015; 48(4); 217-221. doi: 10.1159/000437271

20. Born RT, Bencomo G. Illusions, Delusions and your Backwards, Bayesian Brain: A Biased Visual Perspective. *Brain Behav Evol* 2020; 95(5) 272-285. doi:10.1159/000514859

21. Bruckmaier G, Krauss S, Binder K, Hilbet S, Brunner B. Tversky and Kahneman's Cognitive

Illusions: Who Can Solve Them, and Why? *Front Psychol* 2021; 12. doi: 10.3389/fpsyg.2021.584689

22. Friston K. The history of the future of the Bayesian brain. *NeuroImage* 2012; 62: 1230-1233 doi:10.1016/j.neuroimage.2011.10.004

23. Hipólito I, Kirchhoff M. Breaking Boundaries: the Bayesian Brain Hypothesis for perception and prediction. *Consciousness and Cognition* 2023; Available at https://doi.org/10.1016/j.concog.2023.103510

24. von Helmholtz, H. Concerning the perceptions in general, 3rd Ed. Treatise on Physiological Optics, Vol. III (Translated by J. P. C. Southall 1925 of the 1866 manuscript; reprinted New York: Dover, 1962.) *Opt Soc Am 1925;*26:4.. Available at https://archive.org/details/helmholtzstreati0003jame/page/338/mode/2up retrieved 27 Mar 2025

25. Sox HC Jr. Probability theory in the use of diagnostic tests. An introduction to critical study of the literature. *Ann Intern Med* 1986 Jan;104(1):60-6. doi: 10.7326/0003-4819-104-1-60.

26. Krauss S Wang XT. The psychology of the Monty Hall problem: discovering psychological mechanisms for solving a tenacious brain teaser *J Exp Psychol Gen* 2003 Mar;132(1):3-22. doi: 10.1037/0096-3445.132.1.3.

27. Simons DJ, Chabris CF. Gorillas in our midst: sustained inattentional blindness for dynamic events. *Perception* 1999; 28: 1059-1074. doi:10.1068/p281059

28. Simons D. Selective Attention Test (video). Available at https://www.youtube.com/watch?v=vJG698U2Mvo retrieved 16 Mar 2025

29. Quirkology. Colour Changing Card Trick (video). Available at https://www.youtube.com/watch?v=v3iPrBrGSJM retrieved 16 Mar 2025

30. Potié A, Roelants F, Pospiech A, Momeni M, Watremez C. Hypnosis in the Perioperative Management of Breast Cancer Surgery: Clinical Benefits and Potential Implications. *Anesthesiol Res Pract* 2016:2942416. doi: 10.1155/2016/2942416.

31. Fusco N, Bernard F, Roelants F, Watremez C, Musellec H, Laviolle B, Beloeil H. Hypnosis and communication reduce pain and anxiety in peripheral intravenous cannulation: Effect of Language and Confusion on Pain During Peripheral Intravenous Catheterization (KTHYPE), a multicentre randomised trial. *BJA* 2020;124(3):292-298. doi: 10.1016/j.bja.2019.11.020

32. Slater P, Van-Manen A, Cyna AM. Clinical hypnosis and the anaesthetist: a practical approach. BJA Education 2024; 24(4): 121e128. doi: 10.1016/j.bjae.2024.01.005

33. Klein G. Naturalistic decision making. *Hum Factors* 2008; 50(3): 456–60. doi:10.1518/001872008X288385

34. Klein GA. A recognition-primed decision (RPD) model of rapid decision making. In: Klein GA, Orasanu J, Calderwood R, Zsambok CE, editors. *Decision making in action: models and methods.* Norwood, NJ: Ablex Publishing; 1993; 138–47.

35. Klein G. *Sources of Power: How people make decisions.* Cambridge (Mass.): MIT Press. 1998

36. Engel PJH Tacit knowledge and visual expertise in medical diagnostic reasoning: Implications for medical education. *Medical Teacher* 2008; 30: e184-e188 doi:10.1080/01421590802144260

37. Waag WL, Bell HH. Situation assessment and decision making in skilled fighter pilots. In Zsambok, CE, Klein, G. *Naturalistic decision making.* Mahwah, NJ: Lawrence Erlbaum Associates, Publishers. 1997: 247–54.

38. Dominguez CO. Expertise and metacognition in laparoscopic surgery: a field study. In: *Proceedings of the Human Factors and Ergonomic Society* 45th Annual Meeting, Minneapolis/St. Paul; 2001:1298–303.

39. Gladwell M. *Outliers: The Story of Success.* New York, NY: Little Brown and Company Pubs. 2008

40. Ericsson KA, Charness N, Feltovich P, et al., editors. *The Cambridge Handbook of Expertise and Expert Performance.* New York (NY): Cambridge University Press; 2006Nakayama

41. Gao Q, Hartwig MG. Commentary: Are 10000 hours really the key to adult learning? Perhaps not. *JTCVS Open* 2021;8: 688-9. doi: 10.1016/j.xjon.2021.09.009

42. Wong NC. The 10000-hour rule. *Can Urol Assoc J* 2015; 9(9-10):299. doi:10.5489/cuaj.3267

43. Ericsson KA. Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains. *Acad Med* 2004; 79(10 Suppl): S70-81.

44. Ericsson KA. Deliberate practice and acquisition of expert performance: a general overview. *Acad Emerg* Med 2008;15(11):988-94.

45. Eriksson KA, Harwell KW. Deliberate Practice and Proposed Limits on the Effects of Practice on the Acquisition of Expert Performance: Why the Original Definition Matters and Recommendations for Future Research. *Front Psychol* 2019; 10: 2386. doi: 10.3389/fpsyg.2019.02396

46. Flack J. Situation Awareness: Proceed With Caution. *Human Factors* 1995; 37(1) : 149-57. doi: 10.1518/001872095779049480

47. Endsley MR. A taxonomy of Situation Awareness Errors. In: Fuller R, Johnston N, McDonald N, Eds. *Human Factors in Aviation Operations.* Aldershot: Ashgate Publishing. 1995; 287–92.

48. Schulz CM, Krautheim V, Hackemann A, Kreuzer M, Kochs EF, Wagner KJ. Situation awareness errors in anesthesia and critical care in 200 cases of a critical incident reporting system. *BMC Anesthesiol* 2016;16:4 doi: 10.1186/s12871-016-0172-7

49. Prineas S, Mosier, K, Mirko C, Giuccardi S. Non-Technical Skills in Healthcare. Donaldson L, Riccardi W, Sheridan S, Tartaglia R Eds. In: *Textbook of Patient Safety and Clinical Risk Management.* Cham (CH): Springer; 2021. Chapter 30. 2020.

50. Killgore WDS. Effects of sleep deprivation on cognition. *Prog Brain Res* 2010; 185:105-29

51. Rogers AE. The Effects of Fatigue and Sleepiness on Nurse Performance and Patient Safety. Chapter in *Patient Safety and Quality: An Evidence Based Handbook for Nurses.* Rockville (MD): Agency for Healthcare Research and Quality (US); 2008. Available at https://www.ncbi.nlm.nih.gov/books/NBK2651/ retrieved 16 Mar 2025

52. Tawfik DS, Profit J, Morgenthaler TI, Tutty MA, West CP, Shanfelt TD. Physician Burnout, Wellbeing, and Work Unit Safety Grades in Relationship to Reported Medical Errors. *Mayo Clin Proc* 2018; 93(11): 1571–80.

53. Rivera AJ, Tarsh B-T. Interruptions and Distractions in Healthcare: Review and Reappraisal. *Qual Saf Health Care* . 2010 August ; 19(4): 304–312. doi:10.1136/qshc.2009.033282.

54. Young JQ, Ranji SR, Wachter RM, Lee CM, Niehaus B. "July Effect": Impact of the Academic Year-End Changeover on Patient Outcomes – A Systematic Review. *Ann Int Med* 2011; 155(5):309-15. doi: 10.7326/0003-4819-155-5-201109060-00354

55. Jane Ferguson J, Stringer G, Walshe K, Allen T, Grigoroglou Ashcroft DM, Kontopantelis E. Locum doctor working and quality and safety: a qualitative study in English primary and secondary care. *BMJ Qual Saf* 2024; 33: 354–362. doi:10.1136/bmjqs-2023-016699

56. Baverstock A, Finlay F. Take a break: HALT—are you Hungry, Angry, Late or Tired? *ADC Ed Prac* 2019;104:200. doi: 10.1136/archdischild-2019-317209

57. Gaba DM, Fish KJ Howard SK. *Crisis management in Anesthesiology*. New York: Churchill Livingstone. 1994; 24-33

58. Yentis S. Of humans, factors, failings and fixations. *Anaesthesia* 2009;65(1):1-3. doi: 10.1111/j.1365-2044.2009.06018.x

59. Harmer M. *The Case of Elaine Bromiley: Independent Review of the care given to Mrs Elaine Bromiley on 29 March 2005.* Available at https://emcrit.org/wp-content/uploads/ElaineBromileyAnonymousReport.pdf retrieved 22 March 2025.

60. Matthews WJ, Meck WH. Time perception: the bad news and the good. *WIREs Cogn Sci* 2014,

5:429–446. doi: 10.1002/wcs.1298

61. Schonger M, Sele D. Intuition and exponential growth: bias and the roles of parameterization and complexity. *Math Semesterber* (2021) 68:221–235. doi:10.1007/s00591-021-00306-7

62. Kuhlenschmidt KM, Choi E, Moonmoon K, Blackwell J, Comish PB, Balentine C, Grant J, Park C, Dultz LA, Shoultz, Cripps MW, Dumas Ryan P. Provider Perception of Time During Trauma Resuscitation: A Prospective Quantitative Trauma Video Review Analysis. *J Surg Res* 2022 Jun:274: 207-212. doi: 10.1016/j.jss.2021.12.048. Epub 2022 Feb 18

63. Kaber DB, Endsley MR. Out-of-the-loop performance problems and the use of intermediate levels of automation for improved control system functioning and safety. *Proc Safety Progress* 1997; 16(3): 126-31. doi:10.1002/prs.608160304

64. Gouraud J, Delrome A, Berberian B. Autopilot, Mind Wandering, and the Out of the Loop Performance Problem. Front Neurosci 2017; 11. doi: 10.3389/fnins.2017.00541

65. Ruskin KJ, Ruskin AC, O'Connor M. Automation failures and patient safety. *Curr Opin Anaesthesiol* 2020; 33(6): 788-92. DOI: 10.1097/ACO.0000000000000935

66. Endsley MR, Jones WM. A model of inter and intra-team situation awareness: implications for design, training and measurement. In: McNeese M, Salas E, Endsley MR Eds. *New trends in cooperative activities: understanding system dynamics in complex environments*. Santa Monica: Human Factors and Ergonomics Society. 2001;1–24.

67. Wright MC, Ensley MR. Building Shared Situation Awareness in Healthcare Settings. In Nemeth CP Ed. *Improving Healthcare Team Communication*. London: Routledge. 2017. doi: 10.1201/9781315588056

68. Skog A, Peyre SE, Pozner CN, Thorndike M, Hicks G, Dellaripa PF. Assessing Physician Leadership Styles: Application of the Situational Leadership Model to Transitions in Patient Acuity. *Teach Learn Med* 2012; 24(3): 225-30. doi: 10.1080/10401334.2012.692269

69. Cooper S, Wakelam A. Leadership of resuscitation teams: "Lighthouse Leadership". *Resuscitation* 1999; 42:27–45. doi: 10.1016/s0300-9572(99)00080-5

70. Weller JM, Mahajan R, Fahey-Williams K, Webster CS. Teamwork matters: team situation awareness to build high-performing healthcare teams, a narrative review. *BJA* 2024; 132(4): 771-778. doi: 10/1016/j.bja.2023.12.035

71. Fioratou E, Flin R, Glavin R, Patey R. Beyond monitoring: distributed situation awareness in anaesthesia. *BJA* 2010; 105(1): 83-90. doi: 10.1093/bja/aeq137

72. Carayon P, Wooldridge A, Hoonakker P, Schoofs-Hundt A, Kelly MM. SEIPS 3.0: Human-Centered Design of the Patient Journey for Patient Safety. App Ergon 2020; 84: 103033. doi:10.1016/j.apergo.2019.103033

73. Youssef SC, Haram K, Noel J, Patel V, Porter J, Dagupta P. Evolution of the digital operating room: the place of video technology in surgery. *Langenbeck's Arch Surg* 2023; 408: 95. doi:10.1007/s00423-023-02830-7

74. Stichler JF, Feiler JL. Ergonomics in Healthcare Facility Design, Part 1: Patient Care Areas. *JONA* 2011; 41(2): 49-51. doi:10.1097/NNA.0b013e31820592e6

75. Feiler JL, Stichler JF. Ergonomics in Healthcare Facility Design, Part 2: Support Areas. *JONA* 2011; 41(3): 97-99. doi: 10.1097/NNA.0b013e31820c72a1

76. Martin JL, Norris BJ, Murphy E, Crowe JA. Medical device development: the challenge for ergonomics. *Appl Ergon* 2008; 39(3): 271-83. doi: 10.1016/j.apergo.2007.10.002

77. Ward M, Sujan M, Pool R, Preston K, Huang H, Carrington A, Chozos N. Integrating Human-Centred AI into Clinical Practice. Available at https://ergonomics.org.uk/resource/integrating-human-centred-ai-in-clinical-practice.html retrieved 16 Mar 2025

78. Leong KBMSL,Hanskamp-Sebregts M, van der Wal RA, Wolff AP. Effects of perioperative briefing and debriefing on patient safety: a

prospective intervention study. *BMJ Open* 2017; 7: e018367. doi:10.1136/bmjopen-2017-018367

79. Burgess A, van Diggele C, Roberts C, Mellis C. Teaching clinical handover with ISBAR. *BMC Medical Education* 2020; 20(Suppl 2):459. doi: 10.1186/s12909-020-02285-0

80. Skegg E, McElroy C, Mudgway M, Hamill J. Debriefing to improve interprofessional teamwork in the operating room: A systematic review. *J Nurs Scholarship* 2023; 55: 1179-88. doi: 10.1111/jnu.12924

81. Mitchell SA, Boyer TJ. Deliberate Practice in Medical Simulation. In: *StatPearls* [Internet]. Treasure Island (FL): StatPearls Publishing; 2025. Available from https://www.ncbi.nlm.nih.gov/books/NBK554558/ retrieved 26 Mar 2025

82. Endsley MR. A Systematic Review and Meta-Analysis of Direct Objective Measures of Situation Awareness: A Comparison of SAGAT and SPAM. *Human Factors* 2021; 63(1): 124-50. doi: 10.1177/0018720819875376

83. Coolen E, Draaisma J, Loeffen J. Measuring situation awareness and team effectiveness in pediatric acute care by using the situation global assessment technique. *Eur J Paed* 2019; 178: 837-850. doi: 10.1007/s00431-019-03358-z

84. Jonsson K, Brulin C, Härgestam M, Lindkvist M, Hultin M. Do team and task performance improve after training situation awareness? A randomized controlled study of interprofessional intensive care teams. *Scand J Trauma Res Em Med* 2021; 29:73. doi: 10.1186/s13049-021-00878-2

85. Hunter J, Porter M, Williams B. A novel study of situational awareness among out-of-hospital providers during an online clinical simulation. *Australas Emerg Care* 2023; 26: 96-103

86. Hogan MP, Pace DE, Hapgood J, Boone DC. Use of Human Patient Simulation and the Situation Awareness Global Assessment Technique in Practical Trauma Skills Assessment. *J Trauma Acute Care Surg* 2006; 61(5): 1047-1052. doi: 10.1097/01.ta.0000238687.23622.89

87. Zimmermann C, Fridrich A, Schwappach DL. Training Situational Awareness for Patient Safety in a Room of Horrors: An Evaluation of a Low-Fidelity Simulation Method. *J Pat Safety* 2021; 17 (8): e1026-e1033. doi: 10.1097/PTS.0000000000000806

88. Jaffe, R, Zavodnick, J, Papanagnou, D, Zhang, XC, Diemer, G. Patient Safety Escape Room: A Team Simulation in Recognizing and Reporting Patient Safety Hazards. *Am J Med Qual* 2022; 37 (2):166-172 doi:10.1097/01.JMQ.0000753252.29933.8d

