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Review Article

Human factors in anaesthesia: a narrative review

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Summary

Healthcare relies on high levels of human performance, as described by the `human as the hero´ concept. However, human performance varies and is recognised to fall in high-pressure situations, meaning that it is not a reliable method of ensuring safety. Other safety-critical industries embed human factors principles into all aspects of their organisations to improve safety and reduce reliance on exceptional human performance; there is potential to do the same in anaesthesia. Human factors is a broad-based scientific discipline which aims to make it as easy as possible for workers to do things correctly. The human factors strategies most likely to be effective are those which `design out´ the chance of an error or adverse event occurring. When errors or adverse events do happen, barriers are in place to trap them and reduce the risk of progression to patient and/or worker harm. If errors or adverse events are not trapped by these barriers, mitigations are in place to minimise the consequences. Non-technical skills form an important part of human factors barriers and mitigation strategies and include: situation awareness; decision-making; task management; and team working. Human factors principles are not a substitute for proper investment and appropriate staffing levels. Although applying human factors science has the potential to save money in the long term, its proper implementation may require investment before reward can be reaped. This narrative review describes what is known about human factors in anaesthesia to date.

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Introduction

Humans have physical and cognitive limitations and are fallible. The safety of patients should, therefore, not rely on high levels of individual and team performance but should instead depend on well-designed systems that have been put in place to support staff. Human factors science is part of a scientific principle that accepts and understands that humans are fallible [1, 2], and draws on engineering, psychology, social and physical anthropology to design systems that make it easy for people `to do the right thing´, and difficult or impossible `to do the wrong thing´ [3, 4]. Human factors science is embedded within many safety-critical industries and provides an opportunity to improve safety in anaesthesia and in healthcare in general [2, 4]. The International Ergonomics Association defines human factors as ``*the scientific discipline concerned with the understanding of interactions among humans and other elements of a system*´´, and ``*the profession that applies theory, principles, data and methods to design in order to optimise human wellbeing and overall system performance*´´ [1].

Human factors strategies can be grouped together into four domains and ordered in a hierarchy of controls model according to their likely effectiveness (Fig. 1) [5]. Providing well-designed work environments and equipment to decrease the chance of errors occurring is the strategy most likely to be effective and forms the stable base of the pyramid. Barriers (physical and administrative) aim to `trap´ potential errors, reducing the chance of them progressing to patient and/or staff harm. Not all barriers are equal in their efficacy and this needs to be understood and considered in their use. Mitigations comprise behaviours and working practices that form rescue systems: these reduce harm to patients and staff if a significant error progresses past the design and barriers described above. Finally, education and training form the top of the pyramid and, while essential for safety, cannot compensate for poor environment, equipment and systems. Regardless of how well-trained staff are, errors are likely to occur if they are asked to work in poorly designed environments with poor working systems in place. It is important that the base of the pyramid is the largest part, with commensurate economic investment to provide a stable and effective foundation for safety [6–8]. The hierarchy of controls model described in this paper is based on the `error troika´ model [9] and general human factors principles, which have been used in healthcare [5]. In comparison, the National Institute for Occupational Safety and Health (NIOSH) hierarchy of controls model [10], developed with the primary aim of protecting staff from hazards rather than optimising work overall, is not as transferable a model to healthcare [11].

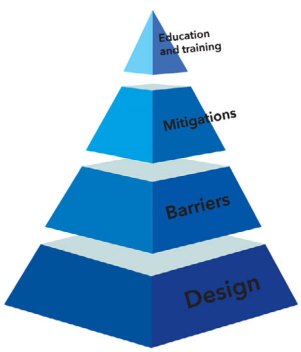

Figure 1 Hierarchy of controls model describing human factors strategies arranged according to their likely effectiveness.

A well-known patient safety concept, the `Swiss cheese model´ [12] (Fig. 2), describes a potential hazard travelling through a system, with slices of cheese representing barriers that prevent hazard progression to an adverse event. The holes in the cheese represent unsafe systems and active errors, and only when these holes are aligned can the hazard pass through. With poorly designed healthcare systems, the holes are large, barriers are less effective and too much reliance is placed on individual practitioners consistently performing at very high levels [12, 13]. This illustrates the `human as the hero´ model [12], where exceptional performance is required to maintain safety every day. As safer systems are designed and implemented,

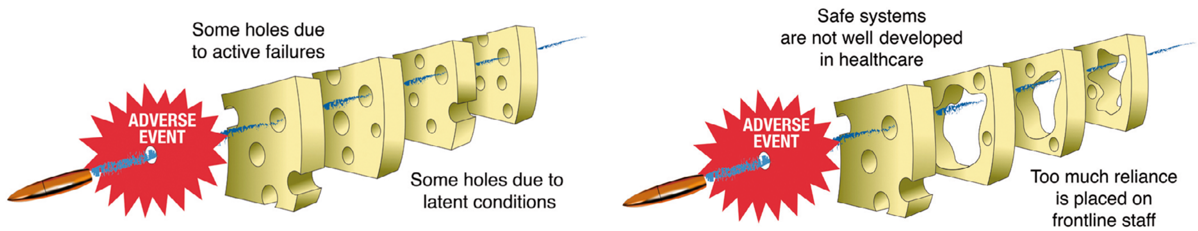

Figure 2 Swiss Cheese model (reproduced with permission from [13]).

the holes become smaller, chance of alignment falls and the risk of the hazard causing an adverse event is decreased.

Impact of sentinel cases on human factors in anaesthesia and wider healthcare

Non-technical skills are an important component of human factors. They include cognitive, social and personal skills that complement technical skills [14, 15] and feature in the barriers and mitigation strategies which reduce the harm and consequences of an adverse event. The value of non-technical skills in anaesthesia has been recognised since the 1990 s [16–18], with the Anaesthetic Non-Technical Skills (ANTS) framework being described in 2003 [18] and the benefits for everyday working and crisis management outlined [17, 18]. Non-technical skill training became much more common following the death of Elaine Bromiley in 2005 [3, 19], with widespread human factors publicity afforded to this by her husband Martin and the anaesthetic profession's response to his work [3, 20]. Martin Bromiley's impact was the dawning of non-technical skills as an issue in anaesthesia safety. This may have led in part to the belief that human factors science is the same as non-technical skills. Bromiley, an airline pilot, emphasised the role of non-technical skills training in improving teamwork, safety and crisis management – such training had been standard in the airline industry since the 1980 s [3, 20]. In addition, he highlighted the importance of a flattened team hierarchy, use of checklists, recognition of situation awareness and strategies to improve it and promoted the integration of human factors training into medical education and healthcare management [3, 20, 21]. Bromiley still regards non-technical skills as critical to safety but recognises that human factors principles around design, systems and work patterns are already embedded at all levels of his industry, providing a firm foundation for the application of good non-technical skills during everyday work [4].

The death of Glenda Logsdail following unrecognised oesophageal intubation in 2020 has raised further awareness of the role of human factors in patient safety [22]. Glenda's husband, Richard, works in the offshore oil industry and is keen that her story is shared, lessons are identified and that the design of safe systems is prioritised to prevent future deaths [23, 24].

Strategies for improving human factors in anaesthesia

Design of medical equipment

Medical equipment and devices range from simple items (e.g. disposable gloves, hypodermic needles and facemasks) to far more complex devices (e.g. ultrasound machines and anaesthesia workstations).

Well-designed medical equipment can reduce the chance of errors occurring with advantages for patients and staff [25]. One example is videolaryngoscopy which has been shown to improve the visualisation of the glottis [26, 27], improve tracheal intubation success rate [26, 27], and reduce the incidence of failed tracheal intubation [26, 27] and oesophageal intubation [26]. Videolaryngoscopy also reduces mechanical stress on the neck, back and shoulders of the clinician, decreasing the likelihood of worker injury [28] and can prevent the transmission of infections during tracheal intubation by increasing the distance between the patient's and operator's airways [29]. The benefits seen in increasing success rates for tracheal intubation with videolaryngoscopy are particularly noticeable when clinicians are wearing personal protective equipment (PPE) [30].

Medical device and equipment manufacturers are required to perform human factors assessments on their products before releasing them to market, according to international standards [31, 32] and Medicines and Healthcare products Regulatory Agency (MHRA) guidance [33]. At present, manufacturers must demonstrate that such assessments occur during the design process, although this often occurs too late for them to make changes if any unanticipated design flaws are detected. In this situation, manufacturers merely have to demonstrate that they have taken steps to mitigate any associated risk, which could be as simple as documenting this in the product instruction manual. Performing human factors usability assessments at an earlier stage of product design and development would allow equipment to be redesigned before being marketed. The human factors assessments performed during the design and development stages, and the resulting mitigations, remain the intellectual property of the manufacturers and are not routinely available to individual hospitals. In-house evaluations cannot expect to uncover hazards and difficulties in use that would be revealed by a comprehensive `use assessment´ by a human factors professional, which can result in equipment with potential hazards finding its way into clinical practice [34].

Design of drug ampoules and packaging

All pharmaceutical companies follow international [35, 36], European and MHRA [37] regulations regarding the colour and design of labelling and packaging; however, this does not always provide optimum readability nor ease of use for clinicians, and drug administration errors continue to occur [38–42]. Different drugs produced by the same manufacturer can look strikingly similar (Fig. 3). Conversely, the same drug produced by different manufacturers can have very different ampoule and packaging design (Fig. 3), resulting in the appearance of drugs changing in the event of a supply chain shortage or change in pharmacy purchasing contracts. Improvements in design have the potential to reduce selection errors associated with drugs that look similar. Potential strategies to improve drug ampoule and packaging design are being investigated.

Design and layout of operating theatres

Operating theatre design and layout should make it as easy as possible for the whole team to work effectively while maintaining patient safety [43]. However, anaesthetists sometimes find themselves working in confined spaces surrounded by cables and pipelines, with the patient monitor difficult to see and infusion devices and urinary catheters awkward to access. There are two principal reasons for this. First relates to operating theatre design. Decisions regarding positioning of fixed features including operating theatre lights, laminar flow hoods, ceiling pendants, pipeline gases, scavenging, suction and power sockets are made when the operating theatre is built. Although this is done in accordance with building regulations, it does not usually consider the way in which the staff will use the space. As a result, staff are forced to adjust their pattern of work to accommodate the operating theatre design. Second is workspace layout. This is the way in which the theatre team arrange moveable equipment within their work area on a daily basis [44]. Compromises are needed between the surgical, anaesthetic and scrub teams who compete for space, a problem that is increasing as the amount and size of operating theatre equipment grows. Human factors tools can be used to identify optimum workspace layouts, and in doing so improve efficiency and reduce the risk of musculoskeletal injuries for staff [43, 44].

Design of equipment storage areas

Well-designed equipment storage areas can reduce the time taken to access equipment in an emergency [45], with examples being standardised layout of cardiac arrest [46] and difficult airway trolleys [47].

Design of safe working practices

Good design of working practices is also essential for ensuring safety. This includes ensuring adequate staffing levels and skill mix, with plans which allow for surges in clinical demand [4]. In addition, staff supervision

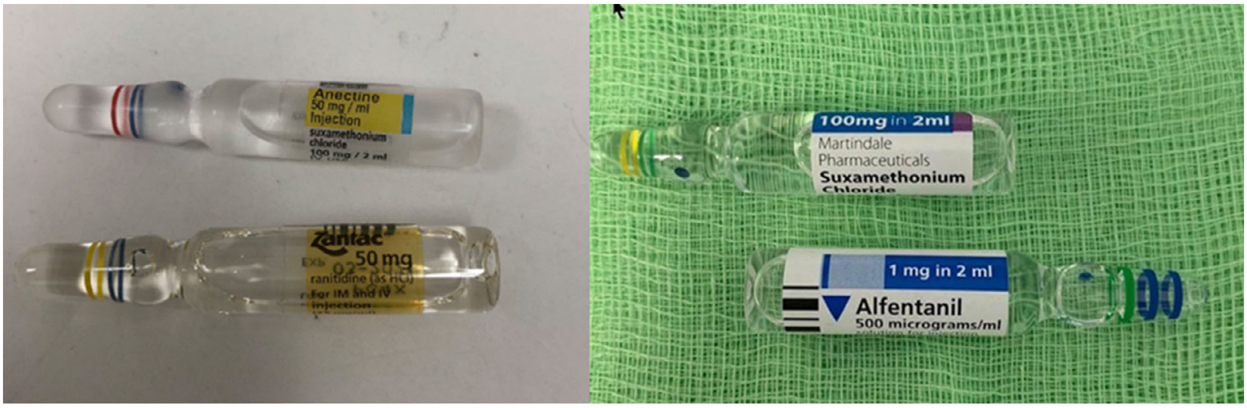

Figure 3 Drug ampoules that look similar, but which contain different drugs.

arrangements, lines of accountability, systems for identification of patients who are sick and/or deteriorating, and systems to allow staff to escalate concerns should be in place [4]. An understanding of demand, capacity and `work as done´ by healthcare staff is needed to design systems and working practices that reflect real life as closely as possible [2, 4].

Barriers

Barriers prevent errors that have occurred from progressing to cause harm to patients and staff; they should be incorporated into working practices when there is no reliable method for `designing out´ the potential hazard.

Administrative barriers

Well-designed policies, protocols and standard operating procedures are easier for staff to use and are more likely to be followed accurately with fewer deviations and omitted steps [48–50]. Nationally agreed policies and protocols with standardised content, formatting and language, can help workers moving between different hospitals, reduce variation in practice and may raise standards [51].

Staff who need to rush while working and/or are anxious due to potentially unachievable workloads are more likely to make mistakes [52–57]. Theatre list planning that acknowledges the additional time required for complex patients, difficult procedures and a high turnover of cases reduces time pressures on staff and allows them to plan and prepare for such cases [58]. Making individual and team workloads more manageable results in improved patient safety as well as reducing the risk of cancellations.

Physical barriers

Physical barriers can prevent harm to staff and patients, with examples including protective goggles and locked theatre doors during laser procedures and simple PPE such as gowns, gloves and masks.

Cognitive aids

Cognitive aids are tools designed to guide staff while they are performing a task or group of tasks [59]. The use of cognitive aids can enhance worker performance, including speed, accuracy and fluidity of task management [59, 60]. Examples of anaesthetic cognitive aids include the Association of Anaesthetists quick reference handbook [61] and the Vortex approach for managing an airway emergency [62].

Algorithms are cognitive aids which comprise an ordered sequence of steps with each step depending on the outcome of the previous one. The 2015 DAS guidelines include examples of well-designed algorithms, with prompts for the team to `call for help´, `declare a failed intubation´, `stop and think´ and `invite ideas from the team´ [47].

Checklists are also cognitive aids, some of which have been shown to reduce postoperative complications and improve surgical outcomes [63–65]. Examples in anaesthesia include the World Health Organization surgical safety checklist [63] and rapid sequence induction checklists [66, 67]. The success of checklists relies on staff being able to use them consistently in the way in which they were designed [64, 65].

Practising non-technical skills during every day working

Non-technical skills are included in the UK Royal College of Anaesthetists' training curriculum [68] and form part of the introduction to the science of human factors for many anaesthetists. Non-technical skills in anaesthesia are well-described by the ANTS system (Fig. 4) [14, 15], and include: communication; leadership and followership [69]; delegation and prioritisation; coping with distractions and fatigue; and managing stress [14]. These can be learned and practised just like technical skills [14, 70].

Situation awareness can be defined as a cognitive skill that involves *`selection and comprehension of information from the world around us to make sense of our work environment´*. It has three components: gathering information; comprehension; and anticipation [14]. In plain English, this means knowing what is going on around you, understanding past events, and anticipating what might happen next [14, 72]. Loss of situation awareness is often associated with the limited capacity of human working memory and the brain being susceptible to `cognitive overload´ in high-pressure situations [72, 73]. Factors that reduce situation awareness include: stress; fatigue; lack of expertise; high workload; and multiple distractions. Education and training, including using simulation, has been shown to improve understanding of situation awareness [14] and provides opportunities to practise strategies to maintain it [14].

Decision-making involves identifying and defining a problem, considering options, selecting and implementing one of those options, and then reviewing the outcome [14]. Decision-making can be learned and improved with practise [14] and is impaired by the same factors that reduce situation awareness.

Task management describes the skills required for organising resources and activities to complete a procedure or plan of action. It can be subdivided into planning and preparing, prioritising, maintaining standards and identifying and utilising resources [14, 15, 69].

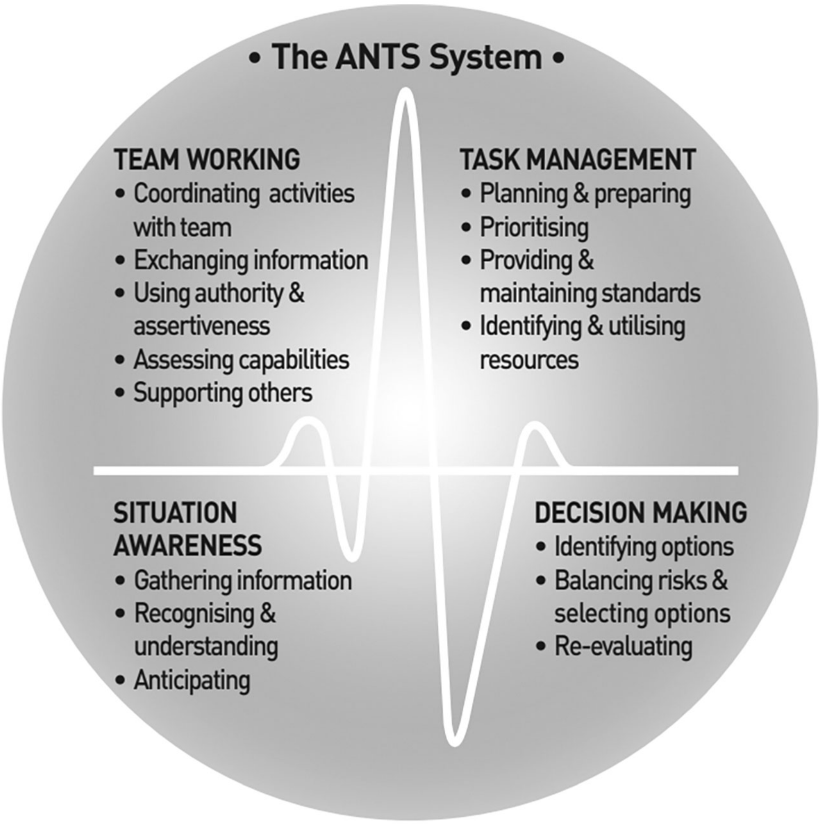

Figure 4 Anaesthetists Non-Technical Skills (ANTS) system (reproduced with permission from [71]).

Effective teamworking is essential for the practice of safe, high-quality anaesthesia [14, 74]. Team working issues including poorly defined roles, lack of explicit coordination, communication problems and failures to resolve conflict have all been identified as contributing to high profile anaesthetic cases that have not gone to plan [3, 19, 20, 22, 75–77].

Effective communication is a non-technical skill that can be learned, developed and improved [14]. It involves the sender encoding and transmitting the desired information followed by receiver receiving, decoding and understanding the information. `Closed loop communication´ or `read-back´, where explicit confirmation is given that a message has been received and understood can help to avoid misunderstandings [78, 79].

There are multiple challenges for anaesthetists when developing and using their non-technical skills. Anaesthetists work in high-pressure environments, often caring for patients who are sick in emergency situations. Anaesthetists often need to process large amounts of information in a limited time with a resultant high cognitive load [80]. Multiple interruptions are common [81], with one study reporting an average of 33 distractions per hour in an operating theatre [82]. Theatre team composition may be different each day and may even change during an operating list. In emergency situations, `flash teams´ form [83]: the members of these teams are unlikely to have had a briefing at the start of a shift and may not know each other's names, roles, skill sets or levels of experience [83]. In all these situations, the use of good non-technical skills can help increase margins of safety.

`Flattening of the hierarchy´ within a team

Good use of non-technical skills can help to `flatten the hierarchy´ within the team, also described as `reducing the authority gradient´ [14]. This can help team members to challenge more senior colleagues if they believe that patient safety is at risk [83–85]. A certain degree of hierarchy within a team is necessary for effective leadership and followership. However, a steep hierarchy, and subsequent failure of team members to speak up (or be heard) when they raised concerns, appears to have played a part in high profile deaths in the UK, including Elaine Bromiley [3, 19, 20], Sharon Grierson [76], Peter Saint [77] and Glenda Logsdail [22]. Graded assertiveness tools such as CUSS (``I'm **c**oncerned´´; ``I'm **u**ncomfortable´´; ``This doesn't feel **s**afe´´;

``top´´) [83, 86] may help empower team members to speak up and provide a structure to use when they do so. These tools work most effectively if senior staff are also trained to `listen down´ for the specific phrases used in such tools.

Task fixation and transitioning from one stage of an algorithm to the next

Task fixation describes the situation when an individual or team make multiple unsuccessful attempts at one technique and become `stuck´ on one procedure or at one stage of an algorithm [87]. Strategies to encourage staff to transition from one part of an algorithm to the next help reduce the risk of this occurring. The Advanced Life Support algorithm gives time-based transition prompts (recheck pulse every 2 min) as well as outcome-based action prompts (shock or no shock depending on rhythm) to help the resuscitation team move through the correct management steps. Examples of anaesthetic cognitive aids which encourage transitioning can be found in the DAS guidelines, with a specified maximum number of attempts at tracheal intubation and supraglottic airway insertion [47].

Mitigations

Mitigations are systems or actions which reduce the consequences of an error that has occurred, with the aim of preventing or minimising subsequent harm to patients and/or staff. Examples of mitigations familiar to anaesthetists include the ready availability of `anaphylaxis boxes´ and the activation of outreach teams in response to early warning scoring systems being triggered. Less obvious examples of mitigations include incident investigation and the associated learning along with strategies and actions to support staff affected following a critical event.

Incident investigation

Incident investigations should ensure that lessons are identified, actions are put in place and their effectiveness is monitored. The investigation techniques used currently in healthcare often scrutinise the actions of staff involved but do not always identify system factors. As a result, investigations may fail to identify robust system changes that could be implemented to prevent the event recurring, and instead just lead to recommendations for additional staff training [88]. A new patient safety incident response framework (PSIRF), based on human factors principles [89], is replacing the existing root cause analysis investigation tools that are currently in use in the UK healthcare system. This framework recommends that critical event investigation teams should include members with human factors training and use human factors tools such as systems engineering initiative for patient safety (SEIPS) [90]. Another human factors tool validated for use in healthcare investigations is the Yorkshire contributory factors framework [91].

Learning from events that go well as well as ones that do not

Safety-I is defined as a state where as few things as possible go wrong, and assumes that errors occur because of identifiable failures or malfunction of specific components of a system [92]. Safety-II is a more recent initiative that focuses on what is going well in a system or process and analyses the associated everyday working practices with the aim of replicating them more widely [92]. To improve patient safety, it is vital that we learn from the many cases that go well as well as from cases that do not go to plan [93–95].

Debriefs and peer support tools following a death in theatre or critical event

The death of a patient in an operating theatre or a critical event where a patient comes to harm may have a devastating effect on staff involved, even if the event was anticipated [96].

Evidence suggests that a psychological debrief for all staff involved in a critical event, for example critical incident stress debriefing, may encourage staff to relive the trauma and may be harmful [97, 98]. An immediate team `check in´, `diffusion meeting´ or `after action review´ for staff involved may be helpful if short (< 2 min), carried out in a non-judgemental and objective manner and generates a list of staff involved to facilitate supportive follow up [99]. Specific tools may be used by appropriately trained staff to structure this [99].

The use of peer support tools, such as trauma risk management (TRiM) [100], have been used in healthcare [101]. They provide a structure for managing the immediate aftermath of a critical event and can reassure staff that a trauma stress reaction is normal after an abnormal event, and this usually resolves with time [101]. In addition, peer support tools provide a framework for identifying staff who may benefit from professional psychological help after such an event and can signpost them to such services [101].

Education and training

Human factors training

The UK Chartered Institute of Ergonomics and Human Factors white paper [2] and Health Education England's patient safety syllabus [102] recommend basic human factors awareness training for all NHS staff. In addition, the Ockenden review [103] recommended annual human factors training for all staff working in a maternity setting. The recommended training includes the role of good design, use of non-technical skills as appropriate for role and an understanding of performance shaping factors [2, 8, 102].

Non-technical skills training

Anaesthetists and their teams can learn and practice non-technical skills during in-theatre training, classroom teaching and by using e-learning programmes. Once the basic concepts are established, simulation training can provide an opportunity for multidisciplinary teams to practise and rehearse non-technical skills and emergency drills/scenarios [73–75, 78]. The use of a dedicated simulation suite allows staff to train away from the distractions of the workplace. Simulation training in an empty operating theatre, recovery bay or clinic room (in-situ simulation) increases realism, enables evaluation of the working environment and working practice design and may prompt improvements [74, 75, 78].

The ANTS system has been used successfully in simulation training centres and provides both a framework to assess non-technical skills and a template for identifying ways to improve them [15, 17, 18, 74]. Similar frameworks have been designed for other staff groups that work with anaesthetists, including: non-technical skills for surgeons (NOTSS) [104]; nurse-anaesthetists' non-technical skills (N-ANTS and NANTS-no) [105, 106]; anaesthetic non-technical skills for anaesthetic practitioners (ANTS-AP) [70]; scrub practitioners' list of intra-operative non-technical skills (SPLINTS) [107]; and the observational teamwork assessment for surgery (OTAS) [108].

Human performance under pressure and cognitive overload

Deterioration in performance in high-pressure situations is well recognised [109] and can be explained by several underlying physiological processes including the ´fight or flight´ response [83], neurophysiological response to cognitive overload [72, 79, 83] and ´limbic hijacking´ [110].

Activation of the ´fight or flight´ response to a minor degree can improve performance, but further activation can lead to prioritisation of gross motor skills over fine motor skills, reducing manual dexterity. In addition, prioritisation of vision over hearing, along with narrowing of the visual field, contribute to poor communication and loss of situation awareness [86].

Working memory has a finite capacity and can typically only hold between four and seven pieces of information at any one time [73, 111]. In a clinical emergency, staff need to process large amounts of information in a short period of time, with the risk that working memory becomes overwhelmed (cognitive overload) [73, 83, 112] resulting in a fall in performance [73, 83, 112].

Limbic hijacking occurs in high stress situations and results in workers exhibiting impulsive reactions to sensory stimuli [110]; these reactions include the ´startle´ or ´surprise´ responses and also contribute to a fall in performance [113].

Worker well-being

The importance of worker well-being in maintaining patient safety is increasingly being recognised [2, 4, 97], with the acknowledgement that ´*well and healthy staff are safer staff*´ [2, 4, 97, 114]. The human factors strategies described within the hierarchy of controls model (Fig. 1) improve the well-being of workers as well as the safety of patients [2, 4, 25]. Human factors professionals investigate routinely the interface between workers and their equipment and working environments to reduce the risk of physical injuries. They also use specific tools to investigate the effect of fatigue on worker well-being and safety, and study the impacts of rota design, working hours and rest pauses [2, 114–116]. Such strategies are relevant to current anaesthetic practice [115, 116].

Several high-profile anaesthetic deaths in recent years have shared common themes including: task fixation; loss of situation awareness; steep team hierarchy; poor teamwork and communication; and a fall in personal and team performance in a high-pressure situation [3, 19, 20, 22, 76, 77, 117]. A follow-up study to the 4th National Audit Project (NAP4) [13] examined 12 cases in detail using a human factors investigation tool [118]. Contributing human factors issues were identified in all cases, the most frequent being: loss of situation awareness (failure to anticipate, wrong decision); job factors (task management, staffing, time pressure); and person factors (tiredness, hunger, stress) [118].

While there is no doubt that good non-technical skills and strategies to maintain optimum human performance can contribute to patient safety, these alone cannot compensate for poor working environments, inadequate systems, understaffing and lack of appropriate financial investment. By implementing human factors design principles to avoid error where possible and incorporating barriers and mitigations to prevent errors that do occur from causing harm, the reliance on high levels of personal and team performance currently required in anaesthesia (and healthcare in general) can be reduced and patient safety and worker well-being can be improved.

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