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The Application of Human Reliability Analysis to Three Critical Care Procedures

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Abstract

Background. Procedures carried out in the intensive care unit are prone to human error. Standardisation has been suggested as an approach for reducing errors. This study used human reliability analysis methodologies to examine commonly performed critical care procedures: endotracheal suctioning; ultrasound-guided right internal jugular vein cannulation; and rapid-sequence intubation.

Methods. The subgoals, or individual steps, required to complete the three procedures were identified using hierarchical task analysis. The systematic human error reduction and prediction approach was then used to identify potential human errors at each subgoal, the level of risk and how these potential errors could be prevented.

Results. Endotracheal suctioning procedure was broken down into 129 subgoals, of which 49 (38.0%) were high-risk. Ultrasound-guided right internal jugular venous cannulation was divided into 224 subgoals, of which 131 (58.4%) were medium-risk, and 20 (8.9%) were identified as high-risk. Rapid sequence intubation was divided into 167 subgoals. A total of 73 (43.7%) of these subgoals were judged to be high-risk.

Conclusions. The use of human reliability analysis techniques can support healthcare professionals to gain an in-depth understanding of how particular procedures are carried out in order to reduce the risk of, and improve training in, how to perform these procedures.

1. Background

Patients in the intensive care unit (ICU) are at high-risk of medical error. Adverse event rates of 20% have been reported in the ICU, with 45% of these events judged to be preventable [1].Therefore, there is a significant potential for reducing human error in such settings. It has been suggested that standardisation of most aspects of intensive care medicine has great potential to improve patient care and outcomes, reduce length of stay, and reduce healthcare expenditure [2]. However, despite promising results from large studies, standardisation has not been widely implemented in critical care [2]. A particular barrier to standardisation is the lack of a common, and agreed, understanding as to how particular procedures should be carried out.

In other high-risk industries (e.g. nuclear power, aviation) there are high levels of standardisation. A common approach used in these industries to standardize task performance is through the use of human reliability analysis. Human reliability analysis consists of a range of techniques and approaches to systematically identify the impact of human error on a system [3]. A specific human reliability technique used to study how people complete a specific task is called task analysis. Task analysis breaks a task down into the component parts that must be carried out in order to complete the task. Task analysis is used to examine how people interact with equipment and their working environment. Task analyses can be organised and presented in a number of different ways, but the most common method is to arrange information hierarchically [4].

In a hierarchical task analysis (HTA), the overall goal (e.g. perform hand hygiene), is broken down into a series of sub-goals that must be completed in order to achieve the overall goal (apply a palm full of alcohol-based hand rub in a cupped hand, rub hands palm to palm, etc.). Examples of the use of the use of HTA in critical care settings include preparing and delivering anaesthesia [5] and the identification and management and communication errors in the ICU [6].

Although the output of a HTA is useful for documenting a procedure for teaching and dissemination [7], it does not allow for the identification and mitigation of potential errors. When standardizing a task a consideration of the potential for error is important and has implications for both the technique and equipment used for completing a task. An approach to analysing potential error has been developed called systematic human error and risk reduction approach (SHERPA)[8]. SHERPA is an approach, first used in the nuclear industry, in which the subgoals derived from an HTA are scrutinized in order to identify where errors in the task may occur and to suggest the most suitable solutions to mitigate these errors [4, 7]. The SHERPA approach explicitly links error reduction measures to the underlying causes of human error in a task.

There are few examples of the application of human reliability analysis techniques in healthcare, as compared to other high-risk industries [7]. This is surprising given the large number of safety critical procedures carried out in healthcare- particularly in critical care settings. Given the potential benefits of an improved understanding of critical care procedures, the aims of this study are to: (1) carry out a detailed examination of three commonly performed ICU procedures using HTA; (2) identify those steps in these procedures that are particularly vulnerable to human error using a SHERPA; and (3) consider the utility of carrying out these types of analyses in critical care settings to inform standardisation and training.

2. Methods

A standard approach for completing a HTA and SHERPA of a procedure was used [4, 5]. This approach consists of three stages: (1) Identification of procedures for analysis; (2) Hierarchical Task Analysis; and (3) SHERPA analysis. Each of these stages are outlined below.

2.1 Setting

The study took place at a large Irish university teaching hospital. Data collection was carried out between April and June 2018.

2.2 Ethics

Ethical approval for the study was received from University College Cork's Clinical Research Ethics Committee.

2.2.1 Identification of procedures for analysis

We wished to analyse procedures that are representative of the broad spectrum of tasks that are routinely performed by both ICU physicians and nurses. Therefore, the procedures that were chosen to evaluate in this study were:

- *Endotracheal suctioning:* the mechanical aspiration of pulmonary secretions from a patient who cannot clear their own secretions, due to the presence of an artificial airway (e.g. endotracheal tube, tracheostomy). This procedure is generally carried out by ICU nurses.

- *Ultrasound-guided right internal jugular vein cannulation:* using ultrasound to introduce a central venous line into the internal jugular vein under sterile technique. This procedure is generally carried out by ICU physicians [9].
- *Rapid-sequence intubation:* an established method of securing the airway in patients who are at risk of aspiration of gastric contents into the lungs. This technique is generally performed in the ICU by a physician, assisted by an ICU nurse [10].

2.3 Hierarchical Task Analysis

Separate HTAs were developed for the three procedures. Data was collected for the HTAs from three sources of data.

2.3.1 Literature review

A literature search was conducted to identify articles relating to appropriate technique and best practice for the three procedures of interest. Three sources were identified and used to construct an initial HTA for endotracheal suctioning through an artificial airway [11-13]. Similarly, three sources were used to construct an initial task analysis for right internal jugular vein central venous cannulation [9, 14, 15]. Finally, four sources were identified and used to guide construction of an initial HTA on rapid sequence intubation outside of the operating theatre [16-19].

2.3.2 Observations

A total of 10 instances of each of the procedures being performed in the clinical environment were video recorded.

2.3.3 Subject Matter Experts (SMEs)

Three consultant intensivists and three clinical nurse managers were recruited as SMEs for the development of the HTAs. The SMEs provided an initial review of the information gathered from the literature and observations. Interviews with SMEs were recorded, and the data obtained was used to refine the three HTAs.

2.3.4 Construction of HTAs.

HTAs for each of the three procedures were constructed by an experienced Trainee Anaesthetist (KR), a Consultant Anaesthetist (DB), and a human factors psychologist (POC). A standard approach was used to develop the HTA [20]. This process is described as follows:

1. The overall *goal* was identified (e.g. complete endotracheal suctioning on an adult patient*)*.
2. The series of steps that need to be carried out to achieve this goal were identified- these are the *subgoals.* It is a matter of judgment as to how detailed these subgoals should be. To illustrate, a subgoal could be 'complete hand hygiene', or it could be more detailed (i.e. apply a palm full of alcohol-based hand rub in a cupped hand, rub hands palm to palm, etc.). The level of detail required was determined by consensus between the two anaesthesiologists carrying out the SHERPA based upon whether further decomposition was impossible or was judged to add little value [20].

3. The circumstances under which each s*ubgoal* is carried out and the order in which they are conducted is identified (e.g. if alcohol rub is available then complete subgoals, x, y, and z, if not, then complete subgoals a, b, and c). In the language of HTA this is called the *plan*.

2.4. SHERPA analysis

The subgoals of the task analyses were evaluated using SHERPA [8]. The SHERPA analyses were carried out by the same two anaesthetists who constructed the HTAs (KR and DB). The two anaesthetists worked together to carry out the SHERPA analysis. Any disagreements were resolved through discussion until consensus was reached. The method used to complete the SHERPA analysis was as follows:

1. Subgoals were classified based on the behaviour involved, from the following: *action* (e.g. inserting a needle), *retrieval* (e.g. getting information), *checking* (e.g. checking that equipment is working), *selection* (e.g. choosing one technique over another), *information communication* (e.g. delivering information to a patient or healthcare provider).
2. Using the classification of error types that is shown in Table 1, errors were determined that could credibly occur during performance of the different subgoals.
3. The consequences of each identified potential error were described. The two anaesthetists classified the probability of an error into one of four levels: (1); ‘low’, <1/1000; (2) ‘medium’, >1/1000 but <1/100; (3) ‘high’, >1/100 but <1/50; and (4) ‘very high’, >1/50 [5].

4. The “recovery potential” of each error was described, i.e. points occurring later in the HTA where the error could be identified before it had an effect were noted.
5. The “criticality” of each error was rated using the three levels: (1) ‘low’, unnoticeable clinical effect; (2) ‘medium’, transient clinical effect but not life threatening; and (3) ‘high’, a potentially life threatening clinical effect [5].
6. The probability and criticality scores were multiplied together to calculate the level of risk. A score from 0 or 2 is considered ‘low-risk’, from 3 to 6 ‘medium-risk’, and 7 to 12 ‘high-risk.’
7. Potential remedial strategies were suggested to prevent each error from occurring or propagating at the individual level, the equipment level, the environmental level and the organisational level.

Table 1: Error classifications used in SHERPA (adapted from [4,5]).

Error type	Error mode
Action	A1 Too long or too short A2 Mistimed A3 Wrong direction A4 Too little/too much A5 Misaligned A6 Wrong object A7 Wrong action A8 Omitted A9 Incomplete A10 Wrong action on wrong object
Retrieval	R1 Information not obtained R2 Wrong information obtained R3 Information retrieval incomplete
Checking	C1 Omitted C2 Incomplete C3 Wrong object C4 Wrong check C5 Mistimed C6 Wrong check, wrong object
Selection	S1 Omitted S2 Wrong selection made
Information communication	I1 Information not communicated I2 Wrong information communicated I3 Information communication incomplete

3. Results

3.1 Endotracheal suctioning

A simplified HTA for endotracheal suctioning is shown in Table 2. The complete HTA, with all of the subgoals described, is provided in Supplemental Material A.

Table 2. Simplified endotracheal suctioning HTA.

	Task	Plan
1	Prepare the patient	*in all cases do 1.1-1.3; optionally do 1.4-1.6 - if using a closed-suction system, 1.4-1.5 can be done concurrently while performing suctioning*
1.1	Perform hand hygiene	
1.2	Place a pulse oximeter on the patient	
1.3	Hyperoxygenate the patient	
1.4	Hyperventilate the patient	
1.5	Hyperinflate the patient's lungs	
1.6	Instill sterile normal saline through the artificial airway to mobilize secretions (perform lavage)	
2	Perform suctioning	*in most cases do one of 2.1-2.2 - if the patient requires a high inspired oxygen concentration or high positive end-expiratory pressure do not do 2.1; do 2.2*
2.1	Use a single-use disposable suction catheter	*do in sequence 2.1.1-2.1.6*
2.1.1	Perform hand hygiene and apply gloves	
2.1.2	Prepare the suction catheter	
2.1.3	Insert the suction catheter through the artificial airway into the trachea	
2.1.4	Apply negative pressure while withdrawing the suction catheter and stabilizing the artificial airway with the opposite hand	
2.1.5	Discard the suction catheter in medical waste	
2.1.6	Remove gloves and perform hand hygiene	
2.2	Use a multi-use closed suction system	*if a closed suction system is not attached to the breathing circuit do in sequence 2.1.1-2.1.5 - if a closed suction system is already attached to the breathing circuit do 2.2.1 do not do 2.2.2; do in sequence 2.2.3-2.2.5*
2.2.1	Perform hand hygiene and apply gloves	
2.2.2	Prepare and attach the closed suction system	

2.2.3	Advance the closed suction catheter through the artificial airway into the trachea	
2.2.4	Withdraw the suction catheter until the tip is out of the artificial airway and secretions have been aspirated	
2.2.5	Remove gloves and perform hand hygiene	
3	Perform follow-up care	*do 3.1-3.2; optionally do 3.3; do 3.5*
3.1	Hyperoxygenate the patient	
3.2	Monitor the patient for adverse reactions	
3.3	Hyperventilate the patient	
3.5	Perform hand hygiene	

A summary of the data from the SHERPA analysis is provided in Table 3, with the detailed analysis provided in Supplemental Material A. It can be seen that the vast majority of the subgoals were ‘action’ behaviours, with an even distribution of interventions across the four levels. The most commonly suggested remedial strategy was hand hygiene (38 subgoals; see Supplemental Material A). The probability of making errors was ‘high’ or ‘very high’ for the majority of the subgoals, with the criticality of the errors ‘low’ for just over half of the subgoals (see Table 3). There was a medium-risk of an error for the majority of subgoals.

Table 3. Summary of SHERPA analysis for the three procedures.

		Endotracheal suctioning	Central venous cannulation	Rapid sequence intubation
	Number of subgoals	129	224	167
Type of behaviour	Action	109 (84.4%)	172 (76.8%)	109 (65.2%)
	Checking	13 (10.1%)	31 (13.8%)	21 (12.6%)
	Selection	7 (5.4%)	17 (7.6%)	15 (9.0%)
	Retrieval	0	3 (1.3%)	10 (6.0%)
	Information communication	0	1 (0.4%)	12 (7.2%)
Probability of error	Low	25 (19.4%)	63 (28.1%)	51 (30.5%)
	Medium	8 (6.2%)	56 (25.0%)	22 (13.2%)
	High	89 (69.0%)	70 (31.2%)	45 (26.9%)
	Very high	7 (5.4%)	35 (15.6%)	49 (29.3%)
Criticality of error	Low	69 (53.5%)	153 (68.3%)	23 (13.8%)
	Medium	11 (8.5%)	28 (12.5%)	19 (11.4%)
	High	49 (38.0%)	43 (19.2%)	125 (74.9%)
Risk	Low	17 (13.2%)	73 (32.6%)	9 (5.4%)
	Medium	72 (55.8%)	131 (58.4%)	85 (50.9%)
	High	40 (31.0%)	20 (8.9%)	73 (43.7%)
Level of intervention	Individual*	118 (27.9%)	154 (32.8%)	163 (26.5%)
	Equipment	104 (24.6%)	96 (20.4%)	138 (22.4%)
	Environment	94 (22.2%)	59 (12.6%)	151 (24.5%)
	Organisation	107 (25.3%)	161 (34.3%)	164 (26.6%)

*Interventions can be identified at more than one level.

3.2 Ultrasound-guided right internal jugular venous cannulation

The simplified HTA is shown in Table 4, with the complete HTA available in Supplemental Material B.

Table 4. Simplified ultrasound-guided right internal jugular central venous cannulation HTA.

	Task	Plan
1	Prepare for cannulation	*If patient is awake and oriented [do in sequence 1.1-1.8] - if patient is sedated or has altered consciousness [do not do 1.1; do in sequence 1.2-1.8]*
1.1	Explain the procedure and conduct procedural time out	
1.2	Perform hand hygiene	
1.3	Organize equipment	
1.4	Position the patient supine, head-down, and with the head rotated to the left	
1.5	Identify landmarks and perform ultrasound survey	
1.6	Perform full surgical scrub and prepare a sterile field	
1.7	Prepare equipment by removing protective sheaths and positioning ergonomically	
1.8	Position yourself at the head of the bed	
2	Perform cannulation	*Do in sequence 2.1-2.16*
2.1	Identify the internal jugular vein and carotid artery with ultrasound	
2.2	Inject local anaesthetic in the skin and soft tissues overlying the internal jugular vein	
2.3	Choose a puncture site and puncture the skin with the introducer needle/angiocatheter	
2.4	Guide the introducer needle/angiocatheter into the right internal jugular vein	
2.5	Confirm venous blood flow from the introducer needle/angiocatheter; if using an angiocatheter, advance it over the needle into the vein and reconfirm venous blood flow	
2.6	Thread the guidewire	
2.7	Confirm venous position of the guidewire with ultrasound	
2.8	Use a scalpel to make a small incision at the point where the guidewire meets the skin	
2.9	Dilate a tract from the skin to the right internal jugular vein	
2.10	Place the central venous catheter at an appropriate depth	
2.11	Remove the guidewire	

2.12	Confirm venous blood flow from all ports of the central venous catheter by aspiration	
2.13	Flush all ports of the catheter with saline and close them	
2.14	Secure the catheter with sutures	
2.15	Dress the catheter with an antimicrobial-impregnated sterile central venous catheter dressing	
3	Perform follow-up care	*Do all in any order 3.1-3.2; do in sequence 3.3-3.5*
3.1	Return the patient to a comfortable position	
3.2	Dispose of sharps and contaminated material	
3.3	Perform hand hygiene	
3.4	Monitor for adverse events	
3.5	Obtain a chest radiograph to confirm position of the catheter	

A summary of the SHERPA analysis is shown in Table 3, with the complete analysis provided in Supplemental Material B. As with the previous procedure, the majority of the subgoals were ‘action’ behaviours. Individual and organizational level interventions were the most commonly identified. The most frequently suggested remedial strategy were good infection control technique (48 subgoals; see Supplemental Material B). Almost half of the subgoals were judged to have a ‘high’ or ‘very high’ probability, and ’high’ criticality of error (see Table 3). There was a medium-risk in two thirds of the subgoals (see Table 3 and Supplemental Material B).

3.3 Rapid sequence intubation (RSI) outside the operating theatre

The summarized HTA is shown in Table 5 (see Supplemental Material C for all of the sub-goals identified in the HTA).

Table 5. Simplified rapid sequence intubation outside the operating theatre HTA.

	Task	Plan
1	Prepare for intubation	*Do 1.1; then do concurrently 1.2-1.6*
1.1	Perform hand hygiene	
1.2	Use a checklist for preparation	
1.3	Prepare the patient by ensuring venous access, optimising medical state, assessing airway, and preoxygenating	
1.4	Prepare the equipment, including monitors, airway equipment, and drugs	
1.5	Prepare the team by assembling all available senior staff, allocating roles, and discussing the plan	
1.6	Prepare for difficulty by going over the plan/back-up plan(s) and addressing team member concerns	
2	Perform intubation	*Optionally do 2.1; then concurrently do 2.2-2.3; then cycle through 2.4-2.6 - if successful intubation at any point, skip to 2.7*
2.1	Apply cricoid force	
2.2	Induce anaesthesia intravenously	
2.3	Give peroxygenation at the onset of apnoea and neuromuscular blockade	
2.4	Perform intubation attempt(s)	*Do in sequence 2.4.1-2.4.2 - if successful intubation at any point, skip to 2.7 - if unsuccessful intubation, do 2.4.3 and repeat 2.4.1-2.4.2 a maximum of three times + one by a senior colleague - if still unsuccessful, do in sequence 2.4.5-2.4.6 and proceed to 2.5.*
2.4.1	Perform attempt at laryngoscopy	
2.4.2	Perform manoeuvres to improve layngoscopic view/ease of intubation, such as changing device/operator/position	
2.4.3	Provide facemask ventilation	
2.4.4	Ensure senior help is summoned	
2.4.5	Ensure front-of-neck access (FONA) set is immediately to hand	
2.4.6	Declare “failed intubation” and open the front-of-neck airway (FONA) set	

2.5	Perform rescue oxygenation	*Attempt all in any order 2.5.1-2.5.2 a maximum of three times + one by a senior colleague - if successful oxygenation do 2.5.3-2.5.4 concurrently - if unsuccessful oxygenation do 2.5.5 and proceed to 2.6*
2.5.1	Provide facemask ventilation	
2.5.2	Ventilate with a 2nd generation supraglottic airway	
2.5.3	Consider waking patient	
2.5.4	Wait for expert help while maintaining oxygenation	
2.5.5	Declare "can't intubate, can't oxygenate"	
2.6	Establish front of neck airway	
2.7	Inflate cuff of endotracheal tube, ventilate through endotracheal tube, and secure endotracheal tube	
2.8	Confirm position of tube with auscultation and capnography	
3	Perform follow-up care	*Optionally do 3.1; do all of 3.2-3.5*
3.1	Perform endotracheal suctioning and/or recruitment manoeuvre	
3.2	Confirm position of endotracheal tube on chest x-ray	
3.3	Monitor for complications	
3.4	Establish follow-up airway plan and document airway alert	
3.5	Perform hand hygiene	

A summary of the SHERPA analysis is shown in Table 3, with the complete analysis provided in Supplemental Material C. Again, the majority of the subgoals were action behaviours. There was an even distribution of interventions identified across all four levels. The most frequently suggested remedial strategy were the use of checklists to standardize practice (29 subgoals; see Supplemental Material B). More than half of the subgoals were judged to have a ‘high’ or ‘very high’ probability of error, with almost three quarters of these errors judged to have the potential to have a life-threatening clinical effect. Almost half of the subgoals were rated as having a high-risk of occurrence (see Table 3).

4. Discussion

Procedures conducted in the intensive care unit are complex and prone to error [1, 21]. It has been suggested that standardisation is an approach to reducing error in critical care settings [2]. In other industries standardisation has been achieved through the use of human reliability analysis techniques such as HTA and SHERPA. This proactive approach is uncommon in healthcare, where there is a much greater reliance on retrospective analysis after an adverse event has occurred [22]. Therefore, the aims of our study were to use HTA and SHERPA to examine three procedures commonly carried out in the ICU and, consider the utility of carrying out these types of analyses for fostering standardisation and training to carry out critical care procedures.

In order for standardisation to be effective, there is a need to be able to establish whether it is possible to identify ‘a correct way’ for carrying out these procedures [23]. This was achieved in the current study, with HTAs constructed for all three procedures evaluated in this paper. Although HTAs may seem similar to a clinical protocol, they differ in that they focus on the behaviours necessary to execute the procedures. Therefore, HTAs complement existing clinical protocols rather than replaces them [5]. Future research should consider how HTAs can be integrated with clinical protocols, rather than seen as add-ons to existing protocols.

Human reliability analysis also has substantial implications for the improvement of the training healthcare professionals. It is broadly recognised that the traditional 'see one, do one, teach one' approach to medical education are inadequate [24]. The traditional approach to learning lacks components known to be important to both learning a procedure, and ensuring that learning has occurred [24]. These components include consistent guidance for the learner, measurement of performance, and feedback by the teacher to the learner in a systematic and structured way [24]. Integrating these components into the training of healthcare professionals to perform a particular procedure requires a clear understanding of the steps in that procedure- as can be provided through human reliability analysis. The development and use of clear, and detailed, human reliability task analyses can form the foundation for approaches to teaching procedural skills such as mastery learning,[25, 26] and fluency training[23, 27, 28].

Although not commonly used in healthcare, mastery learning and fluency training have been shown to be effective as compared to the traditional approach. To illustrate, mastery learning has been found to increase skills in simulated central venous catheter insertion and decrease complications in actual patients [26]. Although the detail included in the supplemental materials is necessary to carry out the SHERPA, and to evaluate the potential for error at each step, it is not suggested that this level of detail is required to teach healthcare providers to carry out the procedures. However, as can be seen from the summary HTAs presented in the results, the HTAs can be simplified. The level of detail of the HTA can be tailored to the needs of the potential user, and the purpose of the task analysis [3]. It is suggested that task analyses could be used to support the use of approaches, such as mastery learning, for a range of critical care procedures.

Appropriate infection control and hand hygiene practices are crucial to patient safety in the ICU [29]. For the endotracheal suctioning procedure, effective hand hygiene practices were the most commonly identified intervention for reducing risk in this procedure. For the internal jugular vein cannulation procedure, good infection control practices were the most commonly identified intervention. These findings can be considered in the context of a recent systematic review of hand hygiene compliance in ICUs that identified 'before aseptic tasks' as having the lowest level of compliance (31.5%) of five World Health Organisation Moments of hand hygiene [29]. This low level of compliance demonstrates the importance of fully integrating good hand hygiene and infection control practices into procedures, rather than being viewed as an additional task. Consideration should be given how appropriate hand hygiene and other infection control practices can be better integrated into procedures in critical care environments.

The HTA and SHERPA methods and analyses reported in this paper have demonstrated that these human reliability analysis approaches have utility in providing an improved understanding of how a procedure is carried out, as well as the associated risks of error in order to consider whether the risk can be reduced or mitigated [7]. This information has implications for standardisation of how a procedure is performed and the identification of 'a correct way' of teaching someone to carry out a procedure. However, an important caveat is that standardisation is not necessarily always appropriate in all critical care activities. For example, healthcare delivery under an ultra-adaptive risk management model (e.g. trauma) relies heavily on the judgement, adaptability and resilience of the healthcare professionals as opposed to procedures and standardisation [30]. Therefore, it is important to identify when and where standardisation may negatively impact performance, as well as considering when and where it can positively impact patient safety.

4.1 Limitations

The subjectivity of the output of this study presents a potential limitation to its generalizability, with input provided from only two SMEs, from one institution. A small number of SMEs is not only a limitation of this particular study, but is an issue with all HTA and human reliability methodologies. Due to the time required to carry out the analysis, it is common for there to be only a small number of participants involved. The HTAs were based upon a literature review, so is not solely based upon the SME opinions. However, particularly for the SHERPA analysis it would have been desirable to have input from a greater number of SMEs.

The use of SHERPA, as opposed to other more advanced HTA approaches (e.g. Cognitive Reliability and Error Analysis Method; CREAM) could be criticised. We reviewed a number of approaches to human reliability analysis, and decided to use SHERPA as it has been used previously in anaesthetic setting [5], it can be applied by clinicians with limited human factors training or support, and focuses specifically on the procedure. However, it is recognised that SHERPA fails to take into account the impact of the context in which the procedure is being carried out. SHERPA also does not consider the systems issues that contribute to poor performance.

Although the human reliability analysis reported in this paper provides a comprehensive description of task-related behaviour, it provides little insight on the cognitive processes of the individual carrying out the procedure. In order to fully understand what the healthcare professionals carrying out the task were thinking about requires an alternative task analysis approach- such as cognitive task analysis [31]. Cognitive task analysis has previously been successfully used in medicine to teach surgical skills [32], to aid in the teaching of percutaneous tracheostomy placement in the ICU [33], and preparation and delivery of anaesthesia [34]. Therefore, future research might consider examining the cognitive processes as the healthcare professional carries out the procedure.

The human reliability analysis reported in this paper was led by clinicians, and not healthcare safety experts. This could be considered a limitation as in other industries, such as nuclear power generation, this type of analysis is carried out by a designated safety expert [7]. However, healthcare practitioner led human reliability analysis also has advantages in terms of the validity of the analysis, as they are the people that actually carry out the procedure.

The main barriers to the widespread use of human reliability analysis in healthcare are the time and resources required to carry it out. However, there are changes occurring in graduate medical education that may make human reliability analyses in healthcare more commonplace. In recent years there has been a move towards a competency-based approach to medical education, and away from the traditional apprenticeship model [35]. A competency-based approach to learning is focused on educational outcomes. Under this paradigm, assessment must demonstrate that the newly trained healthcare professional is competent for clinical practice [36]. Human reliability analysis techniques provide a method for identifying the steps in a procedure which is required to facilitate both teaching and assessment within competency-based education.

5. Conclusion

Human reliability analysis provides a proactive approach to the mitigation and management of risk. The human reliability analyses of the three procedures evaluated in this paper have demonstrated that it can be carried out on critical care procedures, and that the outputs can potentially be used to support standardisation of critical care procedures. The use of human reliability analysis can support healthcare professionals to gain an in-depth understanding of how particular tasks are carried out in order to reduce the risk of, and improve training in, how to perform these procedures.

List of abbreviations

Hierarchical task analysis ; ICU- intensive care unit; SHERPA- systematic human error and risk reduction approach; SME- Subject Matter Expert.

Declarations

Ethics approval. Ethics approval was granted from University College Cork's Clinical Research Ethics Committee, and all participants consented to participation.

Consent for publication. Not applicable

Availability of data and materials. All collected data is available in the supplemental material

Competing interests. The authors declare that they have no competing interests.

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