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Human Error in an Intensive Care Unit – A Cognitive Analysis of Critical Incidents

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Abstract

‘Human Error’ is often assumed to be the prime ‘cause’ of incidents and accidents in clinical systems. This paper investigates incidents in an adult intensive care unit (ICU). Our human error analysis approach stresses the importance of taking cognitive factors into account. The case study presents data drawn from an incident reporting scheme that has been running for over ten years. An in-depth analysis of example cases is carried out which considers human cognitive constraints during task performance. The genesis of erroneous action can thus be considered in relation to the underlying cognition. We embed work practice and the problems encountered in a holistic cognitive perspective, that recognizes the importance of physical and visual input into human cognitive processing. Also, the cognitive analysis can provide pointers to constraints of humans' performance in context. It does not suffice to only consider the behavioural aspect of ‘Human Error’. We argue that understanding of ‘Human Error’ is limited unless full credit is given to the impact that the characteristics of the human cognitive system has on task performance.

Introduction

Clinical Adverse Events: In 1990, the Harvard Medical Practice Study (ref. 1) investigated the occurrence of patient injury caused by treatment - so-called adverse events. It found that nearly 4% of patients suffered an injury that prolonged their hospital stay or resulted in measurable disability (ref. 2). Since most of the precursors to iatrogenic injuries are perceived to be ‘Human Error’ (ref. 3), the possibility of negligence causes great concern. This led to a considerable increase in interest in the causes of human error leading to adverse events (ref. 4).

Learning from Adverse Events: Formalised analysis of the causes of medical adverse events is rare. Rather, a variety of committees and commissions are typically set up locally, meeting regularly to review any cases of iatrogenic injury that has occurred **and** has been brought to attention by the staff involved (ref. 2). The reporting as well as the analysis of these events, however, is subject to local convention. It thus expresses the self-regulating policy of the health care community.

Research into the causes and prevention of human error has made considerable advances in other fields such as aviation and process control. There has been a shift from ‘blaming the human’ (such as the oft-cited ‘pilot error’) to the insight that error invariably occurs in complex systems. The aim now is to create error-tolerant systems that absorb errors through ‘system defences’ and provide redundancy and possibilities for error recovery (ref. 5).

The move away from the blame culture also made possible the introduction of institution-alised, anonymous, and non-punitive incident reporting schemes. Incident reporting schemes concern "near miss" adverse events, i.e. cases in which iatrogenic injury was likely to have occurred, but the hazardous situation could be recovered from successfully. However, even under clinical reporting schemes, in-depth analysis and search for root causes of adverse events does not always take place (ref. 2).

Cognitive Incident Analysis: Instead of only investigating *what happened* in each incident, much can be gained from understanding the underlying *why* of the event. The cognitive ‘mechanism of malfunction’ (ref. 6) can be traced by using cognitive architectures. These provide the basis for cognitive models, which strive to represent some aspects of people's understanding, knowledge, or cognitive processing when performing some task. These models can, therefore, contribute to our understanding of the cognitive limitations interacting with task performance, for example the effects of cognitive load on performance (ref. 7).

Structure of this Paper: This paper focuses on the cognitive modelling of incident data. We will briefly illustrate existing risk management in medicine by an incident reporting scheme employed in an Edinburgh Intensive Care Unit (ICU). First, we will introduce the Edinburgh system, and the cognitive architecture we will employ to model the incidents. In the next section we show how this cognitive architecture can be used to further understanding of the underlying cognition that leads to behavioural manifestations of 'human error'. Following that, we will give an example of how cognitive modelling can complement techniques for the generation of action recommendations. Conclusions and further issues are given in the final section.

The Edinburgh Incident Reporting Scheme

The Edinburgh incident reporting scheme was set up in an adult intensive care unit in 1989. It has been maintained by an anaesthetist who is also one of the ICU consultants. Equipment in an ICU ranges from monitors displaying life sign data, such as heart rate and intra-cranial pressure (ICP), to drug administration equipment, automatic breathing machines, and oxygen humidifier masks. Patient management involves tracking and transcribing monitored vital data, laying and maintaining lines such as endotracheal tubes, and chest drains, and handling equipment, such as three-way taps for drug administration, ventilators and defibrillators.

The incident scheme employed reporting forms that encouraged staff to describe the event in narrative form, as well as noting contributing factors, detection factors, grade of staff involved in the event and that of the reporting staff.

Incidents reported over ten years (ref. 8) fell mainly into four task domains: relating to ventilation, vascular lines, drug administration, and a miscellaneous group.

Incident Categorisation: The categorisation and analysis of human error in incidents and accidents has received considerable attention. Several taxonomies exist, ranging from behavioural classifications (ref. 9) to classification of error according to underlying cognitive mechanisms (ref. 10).

The distinction between varieties of human error according to their cognitive origin plays a significant role in accident analysis because they require different methods of error management and remediation (ref. 11). This paper will use a cognitive architecture as a vehicle for expressing not only expert task performance but also the more realistic error-prone thought and action sequences processed by the human operator. By doing this, the error modelling capability implicit in the comprehensive ICS cognitive architecture is made the focus of inquiry into the underlying cognition of user performance. Such explicit modelling of erroneous performance can thus help to communicate user cognition analyses, and to ground incident analysis and subsequent action recommendation in a cognitive theoretical framework.

Cognitive Modelling

We will use Interacting Cognitive Subsystems (ICS) (ref. 7) to illustrate the modelling of human error within a cognitive architecture. The ICS architecture provides a comprehensive account of human cognition, which has been applied to real-life systems and tasks, such as cinematography (ref. 12) and Air Traffic Control (ref. 13). ICS attempts to bridge the gap between theory-oriented cognitive architectures and cognitive task models (refs. 13; 14). Alternative cognitive task models, such as Task Analysis for Knowledge based Descriptions (TAKD) (ref. 16), User Action Notation (UAN) (ref. 17), or Soar (ref. 18) might have been used. However, they lack the level of detail in ICS's representation of cognitive processes, or, as in the case of Soar, the inherent constraints that these have to satisfy (ref. 19).

Interactive Cognitive Subsystems (ICS): Cognition is represented in ICS as the flow of information between a number of different subsystems, and the processing performed on this data. Each of the subsystems has associated with it a unique mental code in which it represents the information it receives and processes. It will transform its data output into the corresponding mental code of the subsequently receiving subsystems. Each subsystem can receive several input streams and achieve a blending of these data streams under certain circumstances as described below (ref. 12). Each subsystem also has at its disposal a local image store. This serves as an episodic memory buffer of infinite size. A copy of any input the subsystem receives will automatically be copied to the local image store, before being further processed. Figure 2 presents an overview.

Sensory subsystems:	
VIS	visual: hue, contour etc. from the eyes
AC	acoustic: pitch, rhythm etc. from the ears
BS	body-state: proprioceptive feedback
Effector subsystems:	
ART	articulatory: subvocal rehearsal & speech
LIM	limb: motion of limbs, eyes etc.
Structural subsystems:	
OBJ	object: mental imagery, shapes etc.
MPL	morphonolexical: words, lexical forms
Meaning subsystems:	
PROP	propositional: semantic relationships
IMPLIC	implicational: holistic meaning

Figure 1 - The Cognitive Subsystems in ICS

Rarely, however, are the errors resulting in medical incidents described in such detail, or even analysed in terms of underlying psychological factors (ref. 20). Expressing human error within a cognitive model will allow us to investigate and reason about their underlying psychological causes. The model is thus used as a tool for reasoning about human error on a further, more detailed level.

The Edinburgh Categorisation Scheme

In the Edinburgh study, information drawn from the incident reports were categorised into ‘causes’, ‘contributory factors’, and ‘detection factors’ (ref. 8). The categories were arrived at through informal coding of the narrative incident data. This bottom-up approach led to a domain-specific, behavioural categorisation scheme.

‘Causes’ offers the subcategories of Human Error and Equipment Failure. Any incident that has some degree of human involvement is considered a Human Error. Furthermore, the human error incidents are classified as to the various task and equipment domains these refer to, such as "vascular lines related". Thus, ‘cause’ here refers to the task domain of the proximal causal factor. Analysis of the underlying cognition of those proximal causal factors of the incident is not facilitated.

We took two data samples (table 1), one sample covering the first categorisation interval, January and February 1989 (sample89), and the other covering a more recent interval from May to November 1998 (sample98). Both samples cover 25 incident reports.

In the classification of data into the contributing cause categories, combinations of factors are allowed, and are noted frequently in the data sample. For instance, in sample98, one of the predominant factor is ‘Thoughtlessness’ (10 occurrences). Looking at the combinations, however, shows that ‘Thoughtlessness’ is paired with other factors (such as Inexperience with Equipment) in 4 out of 10 incidents.

Table 1 - Causal Categorisation Sample '89

‘Cause’ Occurrence '89		**‘Contributing Factors’ Occurrence '89**		**‘Detection’ Occurrence '89**	
‘Ventilator’:	**10**	Poor Communication:	**14**	D1 Regular Checking:	**11**
‘Vascular line’:	**6**	Poor Equip. Design:	**11**	D2 Alarms:	**11**
‘Miscellaneous’:	**5**	Inexperience with Equipment:	**5**	D3 Experienced Staff:	**8**
‘Disposable Equip-ment’:	**4**	Lack of Suitable Equipment:	**4**	D5 Patient Noticed:	**1**
‘Drug-administration’:	**3**	Night Time:	**3**		
‘Non-disp. Equipment’:	**2**	Fatigue:	**3**		
		Unit Busy:	**2**		
		Failure to Perform Hourly Check:	**2**		

	Thoughtlessness: **2**	

Table 2 Causal Categorisation Sample '98

'Cause' Occurrence '98	**'Contributing Factors' Occurrence '98**	**'Detection' Occurrence '98**
'Drug-administration': **10** 'Ventilator': **8** 'Vascular line': **4** 'Miscellaneous': **4** 'Non-disp. Equipment': **1**	Thoughtlessness: **11** Poor Communication: **8** Inexperience with Equipment: **4** Night Time: **3** Failure to Check Equipment: **3** Failure to Perform Hourly Check: **2** Endotrach. Tube Not Properly Secured: **2** Poor Equipment Design: **1** Patient Inadequately Sedated: **1** Turning the Patient: **1**	D1 Regular Checking: **9** D3 Experienced Staff: **8** D2 Alarms: **2** D4 Unfamiliar Noise: **1** D5 Patient Noticed: **1** D7 Handover Check: **1**

Cognitive Analysis of Errors

One common problem identified in the Edinburgh study is the endotracheal tube coming back out through the larynx. Over time, incident analysis resulted in a list of factors that led the tube to come out. Some of those now constitute 'contributory factors' in the incident data categorisation. One factor is that the tube was not properly secured. Another is that the patient was inadequately sedated, which led to the patient being able to pull out the tube. Judging the appropriate level of sedation is difficult, since oversedating the patient can lead to vital signs being disrupted, while under-sedation increases the possibility of the endotracheal tube being pulled out, which can itself be life threatening.

The tube can also be dislodged when turning the patient. Care must be taken to ensure the tube is long enough to be securely located in the larynx, while being short enough to prohibit it being caught in, for instance, the near-by intra-cranial pressure monitor during the turning manoeuvre. Often, several lines need to be monitored while turning the patient. Thus, dislodging the tube during turning can be facilitated by not perceiving the relationship of the patient's position and the various tubes connecting measurement and drug administration equipment to the patient.

Thus, the scenario described above can be modelled in ICS as shown in figure 2. The visual data, the patient and the position of the lines in relation to the surrounding environment, is received at the visual subsystem (1), sent to the object subsystem for the recovery of a structural description (2), and finally interpreted by the propositional subsystem (3). A loop is entered in order to maintain a stable cognition. The resulting interpretation on the propositional level of the success of the turning strategy influences the further view of the object. If the visual information perceived is inadequate, for instance, the position of the endotracheal tube is neglected, an inappropriate turning strategy will be chosen, and this inappropriate information is sent to limb subsystem (4) to initiate the motor movements.

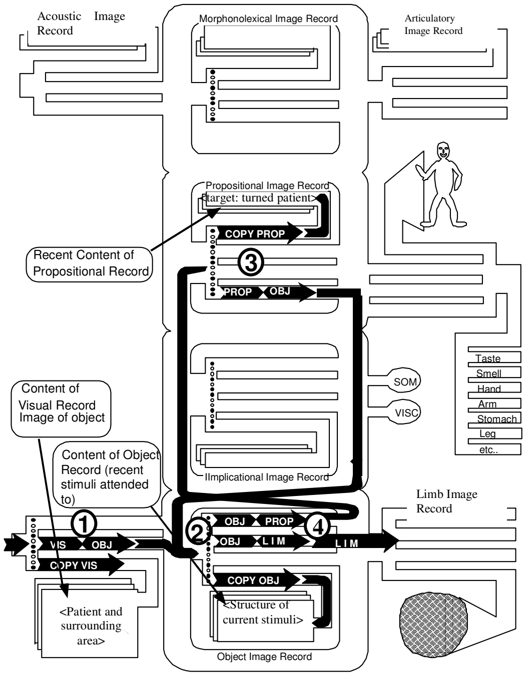

Figure 2 – Lack of Visual Information

This details a perspective on the cause of a dislodged endotracheal tube that emphasises the perception and interpretation of visual information. By modelling the underlying mechanisms of the causes of the incident during turning the patient within ICS, we can shed some light on the processes that are fundamental to the production of the incident as mediated by human error. Contrasted to the categorisation scheme (table 1), this analysis highlights the relationship between two separate 'contributory factors': 'Poor Visibility of Equipment' and 'Turning the Patient'. It is worth noting that these factors are not placed in multi-factor categorisation, but appear as single contributory factors to endotracheal tube incidents in the sample data.

Reasoning about Alternative Error Causes

The third factor listed as a contributory factor for dislodged endotracheal tube incidents is listed as 'Endotracheal Tube Not Properly Secured'. Endotracheal tubes are typically secured in the patient's larynx by means of a cuff (situated on the lower end of the tube) being pumped with air until it sits firmly in the larynx. The failure to secure the tube suggests a 'human error' based on skill-level performance. Attentional resources are only minimally required and the action can be at least partly automised. Figure 3 presents an ICS model that details such as skill-based error leading to a dislodged endotracheal tube.

As can be seen in figure 3, minimal resources are required to perform the task of placing the tube. The fixing of the tube in the larynx by pumping air into the cuff is carried out on a skill-based level, not requiring knowledge-based processing as would be provided by the implicational subsystem. Instead, body state information from the proprioceptive subsystem (1) is sufficient to enable the propositional subsystem (2) to interpret the state of the tube and to send motor movement information to the limb subsystem (3).

However, the task problem might not be based on failures on the skill-base level of performance, but alternatively on failures on a higher level of human cognition. Using ICS, alternative hypotheses as the underlying cognition of the dislodged endotracheal tube class of incidents can be reasoned about.

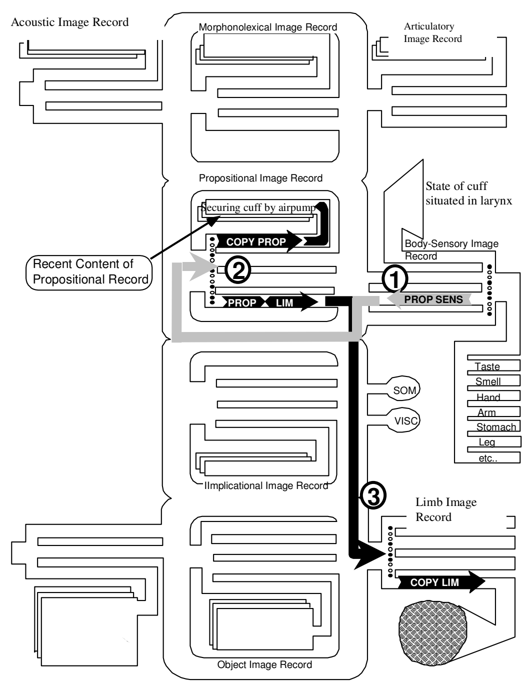

Figure 3 – Skill-based Error

For instance, securing the endotracheal tube via the air cuff was taken as a skill-based task, with the procedural skill readily available.

However, this is not always the case. Not only does the level of staff experience play a significant role, but so do possible exceptions to the rule. For instance, in certain cases, the air cuff on the endotracheal tube is of a different make. Usually, when staff noted that the tube is not properly secured, the first measure is to re-secure the tube by pumping air into the cuff. With the different make of cuff, however, this has a counterproductive effect. In this specific case, pumping air into the cuff will force the cuff, and therefore the endotracheal tube, even further out of the larynx. This special case needs to be considered by staff when re-securing the tube.

Since it is an exception, a mistake on the rule-based level of performance is likely. It is one of the predispositions of the human cognitive system to opt for a well-known and practised rule even when faced with the exceptional situations. Reason (ref. 10) calls this a misapplication of a ‘Strong but Wrong’ rule. In emergencies, this cognitive mechanisms even is enforced, since knowledge-level performance tends to be attenuated during high attentional requirements (ref. 21). The human cognitive system then tends to fall back on well-practised strategies and procedures. Thus, in an environment such as an ICU, where emergencies are part of prototypical work situations, remembering the precise demands associated with rare, exceptional tasks is a resource intensive requirement. This can be modelled in ICS as shown in figure 4.

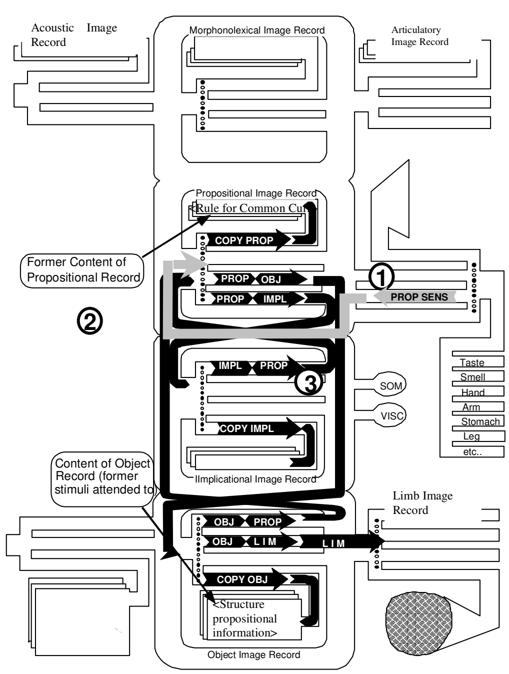

Figure4 - Higher Level Cognition

Figure 4 demonstrates that the processing of an exceptional case involves more cognitive complexity, and requires increased cognitive resources. The body state information (1), being passed on to the propositional subsystem (2), now only presents a small aspect of the cognitive demands posed upon the human. The decision to be taken as to what make of tube is involved, and how the body state information can be interpreted needs to draw on implicational input (3).

This hypothesis, again, has different implications for potential system redesign. Thus, this kind of analysis, taking the impact of cognitive constraints into account, can aid precise and structured reasoning about the incident occurrence.

The examples elaborated above show clearly how different cognitive mechanisms might be implicated in the same overt task performance problem. This multi-way relationship between cause and error might go undetected if systematic error modelling within a cognitive architecture does not take place, this helps analysts to explicitly consider the detailed causes of task performance problems.

Human Error leading to a dislodged endotracheal tube might be grounded in varying cognitive processes, and not stem from one kind of cognitive mechanism alone. Unless these two different causes are considered an analysis might misdiagnose an important problem in the task. Using a cognitive architecture to reason about the potential underlying cognitive error production processes allows work system and equipment designers to investigate the detected task problem in a systematic way.

Currently, the Edinburgh study does not proceed much beyond the "what" phase within the above mentioned analysis model. A structured, formalised analysis framework also helps preventing ‘hindsight’ from biasing error analysis. Attribution of error is a social and psychological judgement process rather than a matter of objective fact. Hindsight view is fundamentally flawed because it does not reflect the situation confronting the practitioners at the scene. Thus, rather than being a causal category, human error should be seen as representing a symptom, and a starting point for investigation (ref. 22).

Often, especially in the case of clinical staff trained for taking on responsibility for their actions (ref. 23), error analysis can be tainted by human cognitive mechanisms such as the 'Fundamental Attribution Error'. According to this, humans are significantly more likely to attribute error occurrence to situational aspects when the error was 'committed' by themselves. However, when looking for reasons why others were involved in 'error', one is most likely to blame the person rather than the situational aspects. This is another reason why an analysis framework is needed that aids objectivity in interpreting the actions of others.

Action Recommendation

In order to arrive at sound and relevant action recommendations, a systematic and structured way of bridging the result of the analysis process to remedial measures is needed. The documentation of this process also plays an important role, for instance to allow monitoring of the effect of the measure.

In industry domains such as aviation and process control, cognitive analysis of error occurrences is often used to point towards remedial actions. For instance, Reece et al. (ref. 24) investigated human error in radiation exposure events. The proximal cause to the incident was situated in the task sequence and, additionally, cognitive failure analysis was carried out. Then the relationship between them was analysed, and thus it could be identified: where training might be most effective; where equipment interface enhancements may be most appropriate; and where job aids (e.g. checklists) might help performance.

This shows how error categorisation, when done according to cognitive level of performance and latent factors, can provide the basis for structured remedial recommendations, rooted in theory. Without error categories being based on sound psychological theory, systematic and relevant action recommendation generation is not possible.

The Edinburgh Study: Action Recommendations: In the Edinburgh study, the incident data was categorised and summarised by the scheme manager. Action recommendations were arrived at in an iterative process, whereby the scheme manager suggested remedial actions and presented those with the summary data to the senior nurse of the ICU. The data was discussed and the rationale for the action recommendations reviewed. This led to a final version of suggested actions for each incident analysis period. Table 2 and 3 show a categorisation of the suggested actions for our two samples (sample89 and sample98).

Table 3 - Action Recommendations for the reporting period Jan/Feb 1989

'Cause' 89		Contributing Factors 89		Detection Factors 89		Action Recommendations 89
Ventilator	**10**	Thoughtlessness:	**14**			**3** Remind Staff…
Vasc. Line	**6**	Poor Equip. Design:	**11**	Reg. Checking:	**11**	**2** change equipment
Misc.	**5**	Inexperience with Equipment:	**5**	Alarms:	**11**	**2** create protocol for equipment use
Disp. Equip.	**4**	Lack of Suitable Equipment:	**4**	Exp. Staff:	**8**	**2** review protocol for equipment use
Drug-admin.	**3**	Night Time:	**3**	Pat. Noticed:	**1**	**1** create protocol for equipment maintenance
Non-disp. Equip.	**2**	Fatigue:	**3**			**1** review equipment
		Unit Busy:	**2**			
		Failure to Perform Hourly Check:	**2**			
		Thoughtlessness	**2**			

Table 4 - Action Recommendations for the reporting period May/Nov 1998

Incident 'Cause' 98		Contributing Factors 98		Detection Factors 98		Action Recommendations 98
Drug-admin.	**10**	Thoughtlessness	**11**	Reg. Checking:	**9**	**4** Remind Staff…
Ventilator	**8**	Poor Communication	**8**	Exp. Staff:	**8**	**1** training viz. new

Vasc. Line **4**	Inexperience with Equipment: **4**	Alarms: **2**	equipment
Misc. **4**	Night Time: **3**	Unfamiliar Noise: **1**	**1** equipment
Non-disp. Equip **1**	Failure to Check Equipment: **3**	Patient Noticed: **1**	maintenance
	Failure to Perform Hourly Check: **2**	Handover Check: **1**	(management)
	End. Tube not		**1** create protocol for
	Properly Secured: **2**		equip. use
	Poor Equip. Design: **1**		**1** review procedure
	Patient Inadequately Sedated: **1**		viz. home
	Turning the patient: **1**		patients' safety

We categorised the suggested actions in the light of system safety design concepts, such as those presented by Reason (ref. 5). Entries under ‘remind staff…’ typically are in the form of a reminder statement, drawing attention to problematic task or equipment characteristics, for instance "Remind all staff of the importance of careful, correct use of 3-way taps on central venous and arterial lines" (February 1989). ‘Change equipment’ is represented by recommendations such as "Particular sort of disposable ventilator tubing used on trial should no longer be used". ‘Create protocol for equipment use’ mentioned for instance "Consider use of small Graseby syringe drivers with smaller volumes of solution".

In the period of May to November 1998, a marked increase in reminder statements can be noted. Following inspection of recommendation data, the dissemination of reminder statements was noted to be the single most often suggested action. In the period August 1995 to August November 1998, there were 82 "Remind Staff…" statements out of a total number of 111 recommendations.

Instead of reacting with reminder statements indiscriminately of cognitive performance level, these could be taken into account when suggesting remedial actions. The categorisation of error according to cognitive mechanisms can also further the understanding of performance problems.

<u>Using ICS to detail risk situations and arrive at action recommendations:</u> The Edinburgh Study also notes incident detection factors, which is often neglected in other reporting systems. It has been suggested that provisions for incident detection and recovery provide more effective safety measures than an approach solely targeting accident prevention or avoidance (refs. 25; 9). However, even if detection factors are noted, they are typically not being analysed in depth. The analysis should include system factors as well as cognitive aspects of the task and work environment. Unless we can monitor those adverse situations which are, and those which are not, reported, we can have little confidence in the accuracy of the system.

The detection factor taxonomy evolved alongside the iterative development of the contributory factors taxonomy. The factors added over time are ‘Having Lines or Three Way Tap Visible’, and ‘Handover Check’. The iteration over the collected incident data thus clarified the importance of handover checks to make up for contributing causes ‘Failure to Check Equipment’ and ‘Failure to Perform Hourly Check’. Without iterative revision and coding of the data categorisation, these factors might have gone neglected. A formalised, cognitive analysis of the incidents can aid the recognition of detection factors and the generation of suggested actions.

For instance, one recurring incident concerned the use of three-way taps. These are used to feed, for instance, two different drugs to the patient via one intravenous line. On changing one of the drug syringe drivers, the corresponding line connecting to the three-way tap is turned off. After the drug change, staff must remember to return the tap settings back to allow both drugs to run.

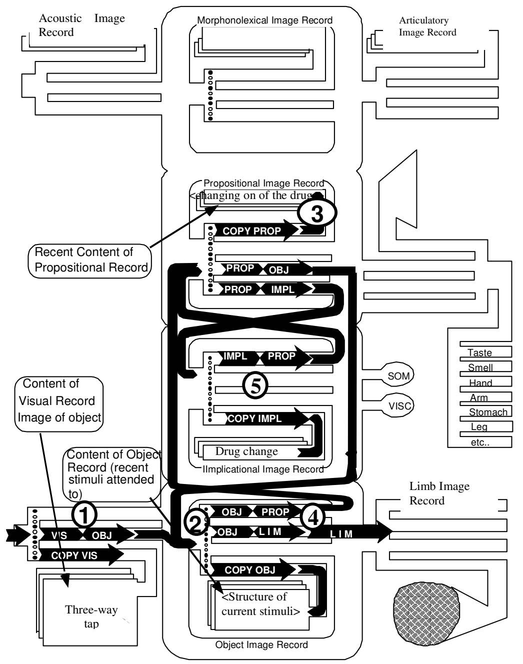

Figure 4 - Three-way tap visibility as Task Cue

Currently, this procedure is being supported by the acronym aide-m■moire T.A.P. – Tap Aligned Properly. Thus, this problem initially prompted 'Reminder' statements in the recommended actions summaries. It was then modified, through an iterative analysis process, to recommend keeping the three-way tap visible, to facilitate staff recognition that the tap was still left in the turned off position. The suggestion to counteract three-way taps being left in the incorrect setting evolved over time. An analysis framework, such as ICS, can point towards weak points in human cognitive task performance such as this. The problem of three-way tap (in)visibility is detailed in ICS in figure 4.

The ICS model illustrates how the process of changing the drug takes over the implicational and propositional subsystem processes. Higher-level, semantic cognition is involved, since active problem-solving is required for the task. The procedure to be followed prescribes the returning of the tap to the correct setting. However, relying solely on the semantic subsystems in remembering all steps in the procedure is insufficient, especially when inexperienced staff are involved (one of the main contributing factors of incidents, see table 1).
By providing prompts for the next step in the procedure, task performance can be pulled onto the rule-based level of performance, rather than requiring knowledge-based problem-solving (ref. 25). Thus, cueing information can be fed into the system via the peripheral subsystems. This principle is often realised, for instance, by providing alarms on equipment. In ICS terms, the peripheral cueing information is in this case being fed in via the acoustic subsystem, for instance by using alarms. Alternatively, and often overlooked, information can also be provided via the visual subsystem.

In the task at hand, the visual subsystem has been focused on observing the status of the syringe driver task. After completion of the task, the resources of the visual subsystem are freed to take in additional status information. The visibility of the three-way tap comes to take a crucial cueing role. After processing the goal hierarchy for selecting a link, the cognitive system can shift its focus back onto the visible three-way tap. Only if the procedural step is remembered, will the propositional subsystem signal anticipation of the three-way tap via internal input into the object subsystem. Thus, the visibility of the tap is crucial to change the propositional representation.

Using ICS to model the underlying cognition of the error provides means of investigating the behaviour trace leading to an incident. Expressing the rationale for different interpretations within a cognitive framework facilitates more precise communication and more detailed analysis. In that way, not only *what* failed in incidents, but also *how* it failed is examined investigation of human error.

Conclusions

There is a need in medicine to recognise the inevitability of error and adverse events (ref. 2). Safety culture that takes this into account in clinical system design is still lacking (ref. 26). There have been some notable exceptions in the recent past where incident reporting schemes were implemented and the identified incidents analysed, such as Runciman et al. (ref. 3) and (ref. 27). However, these focus on the data collection process and somewhat neglect the in-depth analysis, with which valuable insight into incident causation and remedy can be achieved.

Incident investigation schemes often neglect formalised, in-depth analysis of single incidents in favour of a quantitative surface analysis. Also, the crucial role of detection factors is often underestimated. The Edinburgh incident scheme represents those factors in the data collection process, as well as in the generation of action recommendations. However, this process has not been formalised, and is not based on insights gained from cognitive theory.

We have illustrated in this paper how cognitive modelling can be applied to focus more narrowly on the psychological precursors of the human actions leading to incidents.

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References

1. Harvard_University, *Medical Practice Study: Patients, Doctors, and Lawyers: Studies of Medical injury in New York.* 1990, Boston: Harvard University Press.
2. Leape, L.L., *Error in Medicine.* JAMA: The Journal of the American Medical Association, 1994. **272**(23): p. 1851-57.
3. Runciman, W.B., *et al.*, *Errors, Incidents, and Accidents in Anaesthetic Practice.* Anaesthesia and Intensive Care, 1993. **21**(5): p. 506-519.
4. Bogner, M.S., ed. *Human Error in Medicine*. . 1994, Lawrence Erlbaum Associates.
5. Reason, J., *Managing the Risks of Organizational Accidents*. 1997: Ashgate Publishing Limited.
6. O'Hare, D., *et al.*, *Cognitive Failure Analysis for Aircraft Accident Investigation.* Ergonomic, 1994. **37**(11): p. 1855-1869.
7. Barnard, P.J., May, J., *Cognitive Modelling for User Requirements.*, in *Computers, Communication and Usability*, P.F. Byerley, P.J. Barnard, and J. May, Editors. 1993, Elsevier: Amsterdam.
8. Wright, D. *Ten Years of a Medical Incident Reporting System*. in *First Workshop on Human Error and Clinical Systems*. 1999. Glasgow, UK.
9. Hollnagel, E., *The Phenotype of Erroneous Actions: Implications for HCI Design*, in *Human-Computer Interaction and Complex Systems*, G.R.S. Weir and J.L. Alty, Editors. 1991, Academic Press Ltd.: London.
10. Reason, J., *Human Error*. 1990: Cambridge University Press.
11. Maddox, M.E. and J. Reason, *Human Factors Guide for Aviation Maintenance*. 1996, Washington, DC: Federal Aviation Administration/Office of Aviation Medicine.
12. May, J. and P. Barnard, *Cinematography and Interface Design*, in *Human-Computer Interaction: Interact '95*, K. Nordby, *et al.*, Editors. 1995, Chapman and Hall: London. p. 26-31.
13. Buckingham-Shum, S., *et al.*, *CERD: Functionality, Design, Process, and Modelling Issues*, . 1994, Amodeus-2.
14. Grant, A.S. and J.T. Mayes, *Cognitive Task Analysis?*, in *Human-Computer Interaction and Complex Systems*, J.L. Weir G.R.S. and Alty, Editor. 1991, Academic Press Ltd.
15. Simon, T., *Analysing the Scope of Cognitive Models in HCI: A Trade-Off Approach*, in *People and Computers IV, Proceedings of the Fourth Conference of the British Computer Society*, D.M. Jones and R. Winder, Editors. 1988, Cambridge University Press.
16. Johnson, P., D. Diaper, and J.B. Long, *Tasks, Skills, and Knowledge: Task Analysis for Knowledge based Descriptions.*, in *Human-Computer Interaction - INTERACT 1994*, B. Shackel, Editor. 1994, North Holland: Amsterdam.
17. Hartson, H.R., A.C. Siochi, and D. Hix, *The UAN: A User-Oriented Representation for Direct Manipulation.* ACM Transactions on Information System, 1990. **8**(3): p. 181-203.
18. Newell, A., *Unified Theories of Cognition*. 1990, Cambridge, MA: Harvard University Press.
19. Wilson, M.D., *et al.*, *Knowledge-Based Task Analysis for Human-Computer Systems*, in *Working with Computers: Theory versus Outcome*, G. Van Der Veer, *et al.*, Editors. 1988, Academic Press.
20. Busse, D.K. and C.W. Johnson. *Identification and Analysis of Incidents in Complex, Medical Environments*. in

First Workshop on Human Error and Clinical Systems. 1999. Glasgow, UK.

21. Rasmussen, J., K. Duncan, and J. Leplat, eds. *New Technology and Human Error*. 1st ed. Wiley Series: New Tecnology and Work, ed. B. Wilpert. 1987, John Wiley & Son Ltd.: Berlin.
22. Woods, D.D., *et al.*, *Behind Human Error: Cognitive Systems, Computers, and Hindsight*. State of the Art Report, ed. A.W. Schopper. 1994: CSERIAC Crew Systems Ergonomics Information Analysis Center.
23. Berwick, D.M. *Taking Action to Improve Safety: How to Increase the Odds of Success*. in *MedErrors*. 1998. California.
24. Reece, W.J. and S.G. Hill. *Human Performance Analysis of Industrial Radiography Radiation Exposure Events*. in *Human Factors and Ergonomics Society 39th Annual Meeting*. 1995.
25. Rasmussen, J. and K. Vincente, *Coping with Human Errors through System Design: Implications for Ecological Interface Design.* International Journal of Man-Machine Studies, 1989. **31**: p. 517-534.
26. Leape, L.L., *et al.*, *Promoting Patient Safety by Preventing Medical Error.* JAMA: The Journal of the American Medical Association, 1998. **280**(16): p. 1444-47.
27. Battles, J.B., *et al.*, *The Attributes of Medical Event-Reporting Systems.* Arch Pathol Lab Med, 1998. **122**.

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