Cogn Tech Work (2004) 6: 139–147
DOI 10.1007/s10111-004-0155-1

ORIGINAL ARTICLE

Colin F. Mackenzie · Yan Xiao · Richard Horst

Video task analysis in high performance teams

Received: 19 February 2003 / Accepted: 19 January 2004 / Published online: 27 March 2004

Abstract A task-specific video recording effort at a trauma centre was studied. Task analysis methodology and an expert review of videos was used to access cognitive aspects of work and performance. Data collection included questionnaires and video reviews that used a template approach to task analysis and audio recordings of the experts "think aloud" performance assessment. Among 48 video records of airway management, performance deficiencies were identified including communication failures, omission of preparatory and confirmatory checks and lack of patient vital signs monitoring that lessened the margin of patient safety and caused a life-threatening critical incident. The analysis of aggregate data from multiple such videos of airway management allowed detection of the performance problems and development of an equipment design change and a task/communication training algorithm. The performance improvement and the lessons learned from using video as data in a medical domain are described. Targeted video task analysis with expert review may be generalisable to other medical procedures and non-medical domains.

Keywords Airway · Cognitive function · Medical · Performance · Task analysis · Video

C. F. Mackenzie (✉) · Y. Xiao
Charles McC. Mathias, Jr.,
National Study Center for Trauma and EMS,
Department of Anesthesiology,
University of Maryland School of Medicine,
701 W. Pratt Street, 5th Fl, Baltimore,
MD 21201, USA
E-mail: cmack003@umaryland.edu

R. Horst
User Works, Inc.,
Silver Spring, MD, USA

1 Introduction

Cognitive task analysis (CTA) is a means of eliciting knowledge that can make work safe and productive. CTA consists of tools and techniques for describing the knowledge and strategies required for expert task performance and can be used to specify user requirements for training and to identify problematic features of existing interfaces (Chipman et al. 2000). Video recording (including audio on all occasions) is a means to allow access to cognitive aspects of work, not directly accessible to observation, when experts review video records of their own task performance. Overt observable behaviours can then be linked, by the expert, with covert cognitive functions occurring during their task accomplishment. Video recording assists CTA by providing a rich source of stimulus material that is acquired passively from viewpoints not normally available for observation (e.g., from ceiling mounted cameras) in a reusable record of raw data (Mackenzie et al. 1999). Multiple experts can repeatedly review the same raw data and even perform video analyses not designed before the original video data collection. Fine-grained analysis can be performed, not possible with direct observation by repeatedly reviewing critical, brief or uncertain events in expanded time frames. Behavioural and verbal interactions can be analysed for event interpretation and subsequent hypothesis development. As will be discussed later, there are also limitations of video as a data source that may be avoided by the less intrusive method of observation (Mackenzie et al. 1994). Video recording is particularly applicable for examination of team performance in the emergency medical domain and is in daily use as a feedback and training tool in many US trauma centres (Hoyt et al. 1988). However, the methodology for video analysis, consent for video, lessons learned in using video as data and the analysis of video for cognitive function are greatly underutilised in the medical domain.

There are many brief, risky, but beneficial medical and surgical procedures that are carried out during trauma patient resuscitation. Such procedures can be lifesaving, but at the same time, can have life threatening complications. An example of a lifesaving procedure is emergency airway management, which is the first task that is accomplished for patient resuscitation in emergencies. However, difficult airway management accounted for 37% (762/2046) of adverse patient outcomes of which 89% (678/762) were problems associated with airway management (Caplan et al. 1990). The accomplishment of these brief, risky, but beneficial procedures frequently takes place under considerable time pressure, with uncertainty due to the lack of information when patients are admitted emergently from the field.

The objectives of this paper are to illustrate how video task analysis methodology can be used in the medical domain, what lessons were learned by using video as research data and how video can be analysed for cognitive function.

2 Methods

2.1 The background of the studied domain

Airway management is used to ensure patient airway patency and oxygen delivery. Often this is achieved by the passage of a tube into the windpipe (intubation). This airway management (intubation task) is challenging to perform in trauma patients due to time pressure, uncertainty about the patient injuries, unstable vital signs and due to the fact that the team is carrying out other simultaneous resuscitation tasks. The benefits of studying intubation as a tool for video task analysis are firstly, that the activities involved are reasonably well-defined, and intubation has a clear start and finishing point. Secondly, comparisons can be made across different types of cases, as it is used in circumstances with variable time pressure. Thirdly, it occurs frequently enough to allow a reasonable number of procedures to be conveniently video recorded. Fourthly, clinicians generally consider the process of intubation as stressful and high in workload.

In typical settings, six or more care providers work as a team in a 9′ ×12′ ×13′ space around a gurney on which the newly admitted patient is placed. Equipment for monitoring patient vital signs, administering intravenous fluids and performing lifesaving resuscitation procedures surrounds the team. Team members include nurses, surgeons and anesthesiologists who have differing training and expertise. The priorities for initial patient assessment and management follow an established approach proposed by the American College of Surgeons, (Committee on Trauma 1993) known as the advanced trauma life support (ATLS) guidelines. The team members are closely located in the same workspace, and are trained very differently, and the composition of each team changes from patient to patient. These trauma teams have not gone through teamwork training but generally conform to practice guidelines described in ATLS.

2.2 Research subjects

The research subjects were the anesthesia care providers in a trauma centre. The subjects gave consent to be video recorded. Protection of human subjects (both research subjects and patients) was secured through a formal approval process by the institutional review board (IRB). For these studies analysing human performance carried out in the real workplace, the IRB agreed to allow video recording without patient consent because it was not thought feasible to obtain consent consistently in the emergency circumstances in which the video records were made, and precautions were made to ensure patient privacy by procedures such as masking the patients’ faces in video images (Mackenzie and Xiao 2003). The original video records were retained until video analyses were completed and then erased. Video images were acquired from a ceiling-mounted camera and directed so as to minimise patient identifying features (Mackenzie et al. 2003a, b). The research subjects knew when events were being video recorded and they consented to publication of details of video analyses and to use of video clips (from a 30 second to a 3 minute duration) for presentations or in training materials.

2.3 An overview of research procedures

The project of video recording and the analysis of airway management had multiple objectives. Video recording included all team events during trauma patient resuscitation. Video records showed airway management carried out by the anesthesia care providers, with the assistance of other team members. The analyses were carried out with the benefit of the rich sources of supporting documentation about the video recorded event. The design process for data collection, review and analysis is described in Fig. 1.

Semi-structured interviews with subject matter experts (SMEs) were conducted to understand their practices for airway management, to obtain consensus on steps in task analysis and to identify task priorities. Decision trees for the ideal management of abnormalities in patient vital signs were developed iteratively, by consensus reaching discussions, over several meetings with SMEs during which the procedures involved including video acquisition, and the review and analysis were described.

2.3.1 The video review

As soon as possible after the airway management (intubation) was video recorded (usually within hours to several days), the video was reviewed usually both by the lead anesthesiologist whose performance was recorded and another knowledgeable anesthesiology SME. In 22 video records in which it was thought by the reviewing SME that something ambiguous, uncertain or unusual occurred, or if the video record showed a complex tracheal intubation task, then other SMEs reviewed the video record as well. On an ongoing basis, the SMEs were asked to “think aloud” the tasks in which each team member was involved and to verbalise, as much as possible in retrospect, what his/her thought processes were with regard to considering alternative treatment strategies. The videotape was paused from time to time for the SME to relate actual management to algorithmic decision trees developed to define ideal responses to abnormal patient vital signs data. The SMEs were asked to conceptualise the extent to which they considered each choice point, what factors mitigated this choice and whether other factors not currently represented in the decision tree came into play. Based on this description (which was itself audio recorded and transcribed) a data analyst then coded the team’s task activities and behaviours. Each logged entry was related to the time stamp from the video. Explanatory notes described any behaviors or verbalisation that particularly revealed decision-related considerations or team coordination. The second anesthesiology SME was consulted for clarification or further explanation about the clinical activities or discussion that was generated from the observation of the video record. The commentaries from these SMEs usually were audio recorded and transcribed. The reason not every single session was transcribed was that many showed routine care that the SMEs felt showed no covert events or significant cognitive aspects that were not detected by their review. The intubation analysis questionnaire (see below) was used for quantitative and qualitative video data extraction.

The video review process started by either an examination of the admitting area or operating room anesthesia records and surgical summary. The anesthesia records completed by the anesthesia care providers documented events as they were occurring, provided the rationale for intubation and were the legal records of these events. The surgical summary identified the extent and site of injury

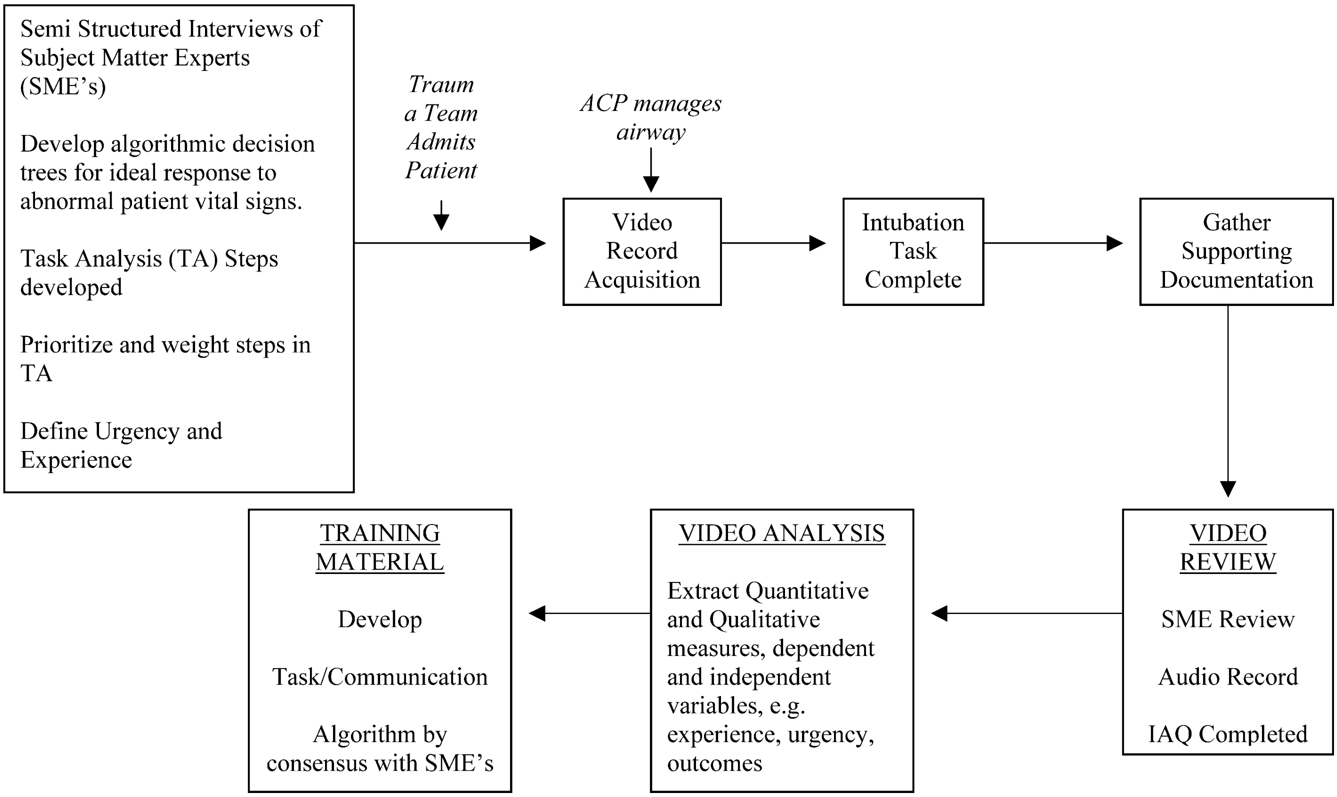

Fig. 1 The design process for the development of training procedures. *ACP* = anesthesia care provider, *PTQ* = post trauma questionnaire and *IAQ* = intubation analysis questionnaire (see the text for details)

and provided an overview of the type of trauma and the physiological state of the patient on admission to the trauma centre.

2.4 Measures

2.4.1 The intubation analysis questionnaire

The Intubation analysis questionnaire (IAQ) was newly developed to systematically allow each SME reviewer to analyse the video record of every intubation in a similar manner. The performance of intubation was defined for the purpose of video data extraction by a task sequence template (referred to as the "rules of intubation"). The task sequence template is shown in Table 1. During the video record review, landmarks in task achievements and event timings were noted and entered into a database together with other assessments required to complete the IAQ. A cohort of 12 experienced (at least 5 years at faculty level) trauma anesthesiologists who worked in the trauma centre where the video records were obtained acted as SMEs both to review their own video recorded performance and those of their colleagues, when they were not involved in the video recorded clinical care.

The IAQ consisted of 110 questions completed during the SME video review. The IAQ included quantitative and qualitative information on patient monitoring, management, status, critical incidents, conformity to "rules of intubation" and timing of events in the intubation task sequence. Subjective assessments were made of psychomotor skills, and decision-making/cognitive skills during intubation. The SME reviewers were asked to identify the following: errors in decision-making during intubation, the appropriateness of drug use and doses (determined by patient vital signs changes and motor responses to intubation), whether or not equipment preparation and vital signs monitoring was adequate, the presence of and type of stressors and the contingencies that may have pointed to different branches of the emergency tracheal intubation decision tree. The timeliness, the use of data and information gathering and the vital signs viewing associated with intubation were evaluated, as well as how well the communications conveyed the patient injuries and team interventions. An overview assessment of communications included effectiveness, the answering of questions, strategy communication and extraneous chatter. The reliability and validity of these measures are unknown. The responses by SME reviewers to each question were aggregated in a database.

2.4.2 Task omission and priority weighting

To determine whether task omissions were due to efficiencies in shedding low priority tasks that could easily be completed at a later, less critical time period, or whether these were errors due to omission of high priority tasks, each task among the "rules of intubation" (Table 1) was prioritised and weighted.

If task omissions were low priority they were hypothesised to be efficiencies due to time pressure rather than omission errors due to a failure to carry out important tasks. To test this hypothesis, the task omissions identified on videotape review were compared before and after a weighting with priority rankings. Task omissions were determined, as shown in Fig. 2, as the mean number of tasks not completed, divided by the total number of tasks, expressed as a percentage. Task weighting gave a low score to a high priority task (Table 1), so that if it was not completed it did little to change the importance of the omission.

2.4.3 Task urgency and anesthesia care experience

Since it was possible that certain cases might be more difficult to the anesthesia care providers than others, we classified the cases into three categories according to the urgency of intubation. These three categories were defined by the elapsed time between the patient's arrival and the start of intubation, occurring within 10 minutes of the patient's arrival (emergency), 11–30 minutes (semi-emergency), and more than 30 minutes (elective). The experience of the person

Table 1 Importance scores for peri-intubation tasks

Task names	EL	SE	EM
Pre-intubation			
Pre-oxygenation	1.50	1.17	1.42
Head positioning	2.20	2.00	2.08
Cricoid pressure applied correctly	1.78	1.33	1.25
In-line stabilisation (neck not cleared)	1.90	1.17	1.27
Suction ready	1.20	1.08	1.25
S_pO_2 monitored pre-induction	1.73	1.83	2.33
$ETCO_2$ monitored pre-induction	3.42	3.33	3.27
BP monitored pre-induction	2.18	2.08	2.67
Heart rate monitoring pre-induction	1.73	1.58	2.25
IV running pre-induction	1.27	1.08	1.25
During intubation			
Intubation equipment ready	1.00	1.00	1.00
Check of NMB before laryngoscopy	3.25	3.42	3.75
Re-oxygenation after three attempts	2.08	2.00	1.91
Re-oxygenation if O_2 sat. $<95\%$	2.00	2.00	2.18
Cricoid pressure until ET tube position determined	1.60	1.00	1.08
Tube cuff inflated to just seal	2.33	2.42	2.42
Tube insertion distance checked	1.92	2.08	2.00
Auscultation of both sides of the chest	1.33	1.33	1.33
Auscultation of both sides of the chest by the intubator	2.25	2.25	2.17
Auscultation of the upper abdomen	2.08	2.00	1.92
After intubation			
Check $ETCO_2$ within 2 minutes of intubation	1.50	1.25	1.50
Listening to the chest after the connection of the ventilator	1.58	1.58	1.58
Tube held till taped or tied	2.42	2.17	2.17
Check of NMB prior to giving the non-depolariser	2.73	3.00	3.42

Consultant trauma anaesthestists scored the importance on a scale of 1–4, with 1 being the most important and 4 the least important. The scores shown here are the averages across 12 consultants and were used for weighing task priorities.

EL = elective, *SE* = semi emergency, *EM* = emergency intubations, *IV* = intravenous fluids, *BP* = blood pressure, S_pO_2 = pulse oximeter, O_2 = saturation, $ETCO_2$ = end tidal CO_2, *ET* = endotracheal and *NMB* = neuromuscular block

who performed intubation (the intubator) was measured by their duration of on-the-job experience: experts were those who had at least 18 months of intubation experience and non-experts had less than two months of experience. These were arbitrary definitions of experts, but were reasonable peer assessments of the participants anesthesia care providers' skills. The psychomotor skills, and the number and duration of direct laryngoscopy (DL) attempts, all of which were collected as part of the IAQ form, were used as dependent variables.

2.5 The training procedure development

The training procedure was developed after video analysis was complete, when performance and other data were aggregated. The consensus among our 12 experienced SME anesthesiologists was used to develop training procedures to overcome the identified task omissions, non-expert performance problems and vital signs monitoring deficiencies found during airway management problems.

2.6 A statistics and population analysis

48 video records showed the intubation task performed by 21 different anesthesia care providers. Among the 48 video records of intubation, 18 (37%) were high-urgency emergency intubations. A total of 12 different SME reviewers were used. Each video record had an average of 2.7 SME reviewers. Inter-rater reliability was assessed by intra-class correlation co-efficiency. 22 video records, from among the 48 showing the intubation task, were reviewed by those whose own care was video recorded and this subset of reviews was used for comparison of experts to non-experts. Unidirectional chi-squared tests were used for comparing frequencies of occurrence and proportions of the tasks accomplished. Paired and unpaired t-tests were used for comparing time durations, and patient monitoring devices used between the different levels of task urgency. Data are presented as mean ± standard error (SE), $p < 0.05$ was considered significant.

3 Results

3.1 Task omission

The tasks omitted among the "rules of intubation" were determined from the review of the video records by SMEs who did not participate in the video recorded clinical care. The task omission rates were weighted by their relative importance scores shown in Table 1. The task omissions in elective, semi-emergency and emergency intubations decreased after weighting, suggesting that task shedding did occur (Fig. 2). However, even accounting for this task shedding, there was still a greater percentage of relatively high priority tasks omitted in preparation for emergency rather than elective intubations. Thus, if our hypothesis were true, that task omissions occurred in emergency intubations because of task shedding, the least important tasks would be shed and we would not expect to detect these differences between emergency and other levels of urgency of tracheal intubation. The most frequently omitted tasks were the lack of a clinical examination of the patient, after the passage of the tracheal tube by the care provider performing tracheal intubation, and a failure of a timely analysis of exhaled gas for carbon dioxide (which confirms correct positioning of the tube in the trachea). An additional finding noted by video analysis but not included in the "rules of intubation," was a failure of the care providers to communicate their clinical findings

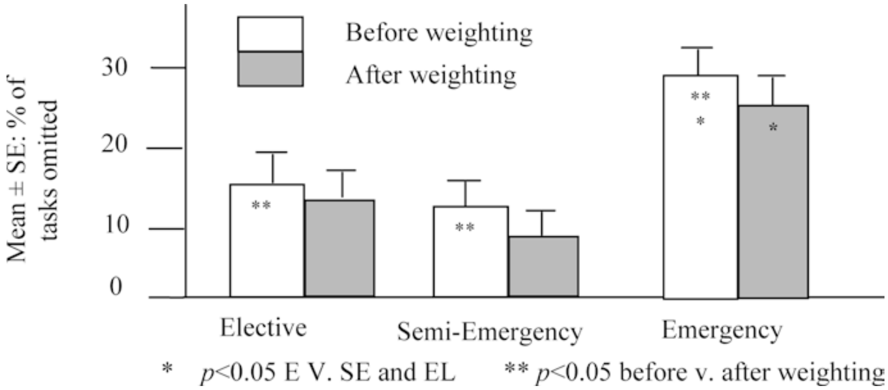

Fig. 2 Comparisons of task omissions, shown as mean ± SE, (among those tasks shown in Table 1) during elective (*EL*), semi-emergency (*SE*) and emergency (*E*) airway management in 42 patients of whom 15 showed emergency, 13 semi-emergency and 14 elective airway management. Twelve SMEs prioritised the tasks that were checked during airway management. On video analysis a low score was given if a high priority task was omitted. Omission of a low priority task considered to be task shedding was given a high weighting that would have the effect of reducing the frequency of task omission. Despite weighting (*gray background*), there were still a greater number of tasks omitted in E than SE or EL airway management. Weighting decreased the percentage of tasks omitted in all three categories of airway management, indicating that some task shedding occurred

when they did examine the patient after intubation. We frequently noted on the video record that three to five different members of the trauma team examined the chest with their stethoscopes without any communication of their clinical findings. Retrospective self-performance evaluation on the PTQ noted failure to communicate information to the team in two urgent intubation tasks. We concluded that on average the tasks omitted for emergency intubations (clinical exam, communication, and CO_2 analysis) were omission errors of important tasks, not task shedding.

3.2 Expert vs. non-expert performances

The results of the analysis of completed IAQ forms from 22 videotapes reviewed by SMEs who participated in the video recorded care, determined if experts performed better than non-experts in the task of intubation. Intraclass correlation coefficients among different raters were 0.2–0.99 (fair to excellent). The correlation coefficients for objective data such as questions about the timing of events was 0.99, whereas a subjective assessment such as "intubation rated as very difficult" was only moderate at 0.57.

The duration of accomplishing intubation by expert and non-expert intubators was greater ($p < 0.05$) in non-experts to complete the first DL, and the time from the DL start to the cuff inflation ("cuff up" in Fig. 3) after tracheal intubation (which signals the end of the task to make an airtight seal and allow mechanical ventilation). However, the number of DL attempts was no different (Fig. 4). Psychomotor skills were subjectively evaluated among the experts and non-experts; experts were thought to have greater skills during elective intubations, but comparisons during semi-emergency and elective intubation showed no differences.

3.3 Vital signs monitoring

The number of physiological vital signs monitors used to provide patient data to the anesthesia care providers during patient care was obtained from the video records showing which vital signs monitors were in use, and was recorded on the IAQ (Table 2). The differences found could be considered a surrogate for the situational

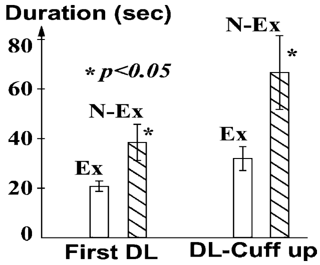

Fig. 3 Comparisons of durations (seconds) to completions of direct laryngoscopy (*DL*)—(the passage of an instrument into the mouth to allow visualisation of the vocal cords) and inflations of a cuffed tracheal tube (DL to "cuff up") among experts ($n = 11$) and non-experts ($n = 12$)

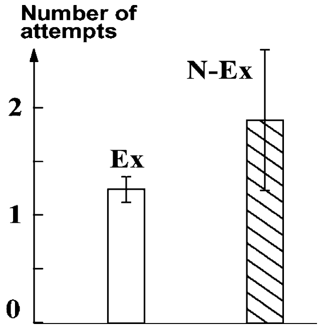

Fig. 4 Comparisons of the number of attempts to accomplish a passage of the tracheal tube through the vocal cords (intubation) among experts (*Ex*) and non-experts (*N-Ex*)

awareness of patient status. Among the five vital signs of O_2 saturation, end-tidal of CO_2, blood pressure, electrocardiogram and heart rate, there were mean 4 ± SE 0.11 vital signs monitored for 15 elective intubations and mean 2.8 ± SE 0.16 monitors in use for 18 emergency intubations.

Video records enabled quantitative data to be extracted about events, e.g., pre-oxygenation before induction of anesthesia (a safety feature to maintain blood oxygen levels during the induction of anesthesia and intubation) was shorter ($p < 0.05$) before induction and intubation for emergency than elective intubations. In analyses performed while data collection was ongoing, it was noted among the first 23 records of intubation, (that of 5/11 elective intubations), in only 1/12 emergency intubations performed in the patient admitting area, was end-tidal carbon dioxide ($ETCO_2$) monitored before intubation (Table 2). This difference triggered a search that identified the cause as being due to the design of the resuscitator bag used for initial ventilation in the patient admitting area. The resuscitator bag had no port for connection of the $ETCO_2$ monitor, whereas an anesthesia circuit (which already includes the connection to the $ETCO_2$ monitor) is used for ventilation in the operating room.

The video analysis did identify several ergonomic factors, which make airway management more cumbersome and less ideal in the patient admitting area than in the operating room. There is more space and there are fewer people around the head of the patient in the operating room. Patient physiological monitors are placed more conveniently alongside the patient's head next to the anesthesia care providers rather than behind them as occurs in the patient admitting area. Video data was used to suggest a re-design of the patient admitting area that allows more access for patient examination, therapy and diagnosis (Harper et al. 1995).

3.4 The psychomotor activity

The psychomotor activity required to intubate the trachea appeared to be increased for emergency intubation. Only one elective intubation required multiple (two) attempts whereas five of 12 emergency intubations took a mean of three attempts before tracheal intubation was achieved. Despite the greater number of attempts, the time between the insertion of the laryngoscope (an instrument to visualise the larynx and allow tracheal tube insertion) and ventilation through the successfully placed tracheal tube was no different (Table 2). In emergency intubations, the patient's condition was more critical than those requiring low-urgency, elective intubations. In emergencies, less patient monitoring information was available and the intubation task was more difficult and performed at a faster pace. Four components of task complexity were identified that could give rise to task shedding in high urgency intubation; these included multiple concurrent tasks, uncertainty, changing plans and compressed work procedures with a high workload.

From a video review of the initial 23 records, it was noted that in no elective intubations, but in six of 12 emergency intubations, listening to the chest was delegated to a non-anesthesia team member. This task shedding suggests there was a greater workload associated with an emergency than elective tracheal intubation. Monitoring of $ETCO_2$ is a double-check to ensure that transmitted sounds from intubation of the esophagus (when no $ETCO_2$ is detected) are not confused with breath sounds from ventilation of the lungs. Observation of the $ETCO_2$ monitor occurred later ($p < 0.05$) after an emergency than elective tracheal intubation (Table 3) giving rise to uncertainty about intubation.

At least two circumstances (a lack of available intravenous access and as a result of this the injection of drugs into the tongue) occurred in real life in association with the emergency management of tracheal intubation. These are not described in the literature as problems occurring during airway management, and therefore, they do not appear in any management algorithms or simulations of emergency airway management. Lack of intravenous access is an increasing problem, because intravenous drug abuse causes the traditional access veins to be unusable.

Table 2 The monitors used: the number of patients (%) of the total $n = 48$ at each level of airway management task urgency

	Elective	Semi-emergency	Emergency
SaO_2 (%)	12 (80)	15 (100)	15 (83)
$ETCO_2$ (%)	7 (47)	9 (60)	4 (22)
BP (%)	13 (87)	15 (100)	14 (78)
ECG (%)	15 (100)	15 (100)	17 (94)
HT (%)	15 (100)	15 (100)	18 (100)

SaO_2 = oxygen saturation, *$ETCO_2$* = end-tidal CO_2, *BP* = blood pressure and *ECG* = electrocardiogram

Table 3 Task durations of intubation events. The mean and the SE of the duration (seconds) of events in the intubation sequence among 11 elective and 12 emergency tracheal intubations

Event	Emergency intubation	Elective intubation
Preoxygenation before anesthesia	234 ± 12.5[a]	92 ± 6.0
Preoxygenation before DL	310 ± 10.2[a]	145 ± 6.1
Duration of DL	31 ± 2.1	32 ± 2.4
Duration: DL to ventilate	41 ± 2.5	30 ± 1.3
Duration: ventilation to listen to chest	10 ± 0.7	38 ± 5.9
Duration: ventilation to $ETCO_2$ observe	52 ± 5.3[a]	205 ± 16.8

[a] Significant at $p < 0.05$

3.5 Performance improvements

The video analysis showed, in the majority of instances, exemplary airway management and skilled and creative responses to the unusual events that occur with relatively high frequency in emergency patient management (Mackenzie et al. 1996a). However, one of the semi-emergency tracheal intubations resulted in prolonged uncorrected esophageal intubation and has been previously reported in Mackenzie et al. 1996b. Of 48 video recordings, 11 (23%) showed occurrences of incidents that were deemed to be performance deficiencies. A total of 28 independent performance deficiencies involving airway management were identified (Mackenzie et al. 1996a). The types of deficiencies included occurrences were grouped under five general headings: communication failures among the team, an omission of listening to the chest to identify ventilation after intubation, lack of timely patient vital signs monitoring, failure to check the mechanical ventilator before the patient connection and a lack of adherence to standard operating procedures for airway management during the induction of anesthesia and tracheal intubation. The shortcomings identified are unlikely to be unique. Other trauma centres have used video recording for training purposes and have found a similar pattern of performance deficiencies in adherence to management protocols (e.g., Hoyt et al. 1988). Abnormal patient vital sign management decision tree differences occurred in five emergency, but no elective tracheal intubations. In one emergency intubation an event unique to all the SMEs occurred and was reported (Mackenzie et al. 1994). Two other events were detected that neither appeared in our decision trees nor have been described in management algorithms or training simulations of emergency airway management.

Many system failures were found during the course of the video recording of tracheal intubation, including a poor design of the alarm system of the mechanical ventilator (it cannot be left switched on in ''ready mode'' without a continuous alarm, unless connected to a patient), a lack of a port for sampling for CO_2 in the manual ventilating device used immediately before and after emergency intubation and communication failures due to noise from adjoining trauma patient admitting areas. These events and system failures were rectified by equipment design changes and procedures incorporated into training procedures and the task/communication algorithm.

4 Discussion

4.1 Video analysis

Video analysis showed that task shedding and short cuts are taken during emergency airway management and these task omissions can lessen the margin of safety for patients. Many issues including the failure of $ETCO_2$ monitoring, the delay in observing $ETCO_2$ and the fewer preparatory checks completed before emergency intubation are procedural issues that could be improved by training. The video record allowed the identification of why there could be uncertainty about patient status during emergency airway management because the physiological monitors were underemployed. In addition, some of the errors in management (e.g., the critical incident of uncorrected esophageal intubation) may be avoided because of warnings provided by these physiological monitors, which are available within arms-reach of anesthesia care providers. As noted in an analysis of pilot errors in the cockpit, problems encountered are often due to the crew's failure to use resources that are readily available (Helmreich 1984). Task shedding might be deemed necessary because of the time pressure to expedite the induction of pain relief with anesthesia and to secure the airway in emergency circumstances when the patient is suffering from a lack of oxygen or is in severe pain. Workload is compressed and there is peer pressure from other members of the resuscitation team to induce anesthesia so that surgical procedures (e.g. insertion of tubes into the chest) can be achieved quickly. The lack of differences in performance of semi-emergency and emergency intubations between experts and non-experts may be because the non-experts, for patient safety reasons, were closely supervised by an expert anesthesiologist. During elective intubation, these non-experts were given sufficient leeway to allow evaluations of their unaided expertise. The problem revealed by video analysis and confirmed by SME review was that none of the anesthesia care providers were aware of the great importance of early monitoring of $ETCO_2$ in emergency intubations. They had not realised the design fault (the lack of a port to allow connection of the CO_2 analyser) in the resuscitator bag that prevented this from being easily accomplished. This important task was shed in one critical event that resulted in a failure to detect esophageal intubation. Confirmation of correct tube placement is vital to all patient resuscitations so that this delay in observing the $ETCO_2$ monitors after emergency intubation suggests that task prioritisation was inappropriate.

As a result of our findings an equipment design change (the insertion of a CO_2 analyser connector) was made, and a task/communication algorithm was developed to correct deficiencies in timely clinical exams, communications and $ETCO_2$ analysis. The equipment design change enabled CO_2 analysis during preparatory pre-oxygenation and immediately after tracheal intubation. The training algorithm clarified the most efficient sequence of tasks and communications. Such communications and tasks when employed as recommended in the algorithm ensure the avoidance of common errors in checks and communications during tracheal intubation.

4.2 Interpersonal human factors

Airway management incidents in this study were documented in real time because of the video record. Thus, the reports of these video recorded events do not suffer so much from factual uncertainty as would retrospective reports from memory. Viewing the video allows participant care providers and SMEs to discuss what happened, and to recognise events in retrospect that were not noted or thought to be important at the time.

Failures of team communication can be reviewed in the video record to determine what occurred. In one instance, both the anesthesia care providers failed to communicate to the surgeon team leader that the ventilation was adequate by face mask and that they should remain in this holding pattern. There was time and peer-pressure stress induced by the surgical team leaders in order to intubate immediately and immobilise the combative patient so that the surgical aspects of resuscitation could proceed expeditiously. Such social pressures are difficult to document without the video record and commentary by care participants during video review.

4.3 The video record as research data

There are both strengths and weaknesses in the analysis of the video record of real patient management for education, quality assurance, human factors and ergonomic research. The major advantages are that the participant anesthesia care providers are not dependent as much on memory, as the video image and audio recording recreate the event, including comments by the team members and alarms that might not have been heard or noted at the time. In our experience, discussions among the participants, care providers and SMEs provided additional information that would not necessarily have been revealed without the video image and audio recording. It would have been more difficult to target points where covert events could be revealed by participant SMEs reviewing their own care or where performance could have been changed, without the video image and audio channel. The participant anesthesia care providers found video analysis useful and they noted that it allowed them to reflect on their performance in greater detail than is possible without it. They often found it revealing to discuss the video with the non-participant SME who could identify that the management was not ideal patient care. It was only on reviewing the videotapes that it became apparent how their performance could be improved.

The weakness of video analysis is that it is tedious and time-consuming. It is difficult to accurately estimate how much time was required to analyse each of these videotapes because much work was spent in the development of the analysis system and the database necessary to facilitate the video analysis of these cases and others (Mackenzie and Xiao 2003). As an example, about 10 hours were spent in the discussion, the viewing and the transcription of the eight-and-a-half minutes of video of prolonged uncorrected esophageal intubation, reported in great detail (Mackenzie et al. 1996b), whereas, aggregated data obtained from the template analysis using the IAQ took about 30 minutes for 10 minutes of video recording.

Other weaknesses of video analysis are that even with a two-microphone system, it is difficult to pick up all the utterances, and the audio record could be improved. However, we believe it would be more obtrusive to equip the anesthesia care providers with microphones. The video image does not include the entire field of view and cannot identify events occurring off the screen, though the audio channel can be helpful. In analysing a video image with the physiological data overlaid there is a tendency to think that the participants were aware of this data, when in reality, this is unlikely because of selective attention to other aspects of anesthesia care. Because analysis occurs after-the-fact, the anesthesia care providers have time to rationalise the decisions made, as they are aware of the outcome. Thinking aloud, and interviews conducted in the middle of case management have been used in simulated anesthesia cases to overcome this problem (Howard et al. 1992; Gaba and DeAnda 1988). The video analysis of such real events will be important in the development of the database necessary for simulation and to improve anesthetic practice and equipment in the future. We believe it is by the systematic study of such real critical incidents that the mechanisms involved in their genesis will be understood and from these analyses preventive measures or particular approaches to training may be devised. This level of effort to collect and analyse video records may only be warranted for important research questions. The successful use of this technique is dependent on careful and extensive study design before the data is collected to insure the research questions are adequately addressed. However, in spite of the difficulties associated with this data collection strategy it is a powerful technique that allows for exploration not possible with other techniques when applied in the real dynamic and stressful workplace.

4.4 The cognitive function from the video review

Insights into *team* cognitive function can also be ascertained from video records by the review of verbal communications recorded, as in previously published reports (Xiao and Mackenzie 1997). Many studies of cognitive activities were based on verbal data, but in the real environment, many communications are non-verbal. As we have illustrated in this paper, exemplary cognitive analysis can be greatly assisted by the video recording of individual cases that are unusual (such as the esophageal intubation). In the trauma centre, multiple video recordings with detailed retrospective accounts and substantiating records have enabled us to assess the usefulness and potential generalisability of this methodology for accessing cognitive aspects of work. Covert cognitive functions can be identified by clinicians when reviewing their own video recorded clinical care. The process of identifying task performance factors using a task template is efficient (typically 3:1 ratio analysis: real video time) and it allows an aggregation of multiple occurrences of the tasks. We have found it particularly revealing to compare data from the aggregated tasks at two levels of urgency as a means for identifying frequently recurring performance omissions. Exemplary cognitive analysis enables the use of individual cases to illustrate how changes in practice can avoid non-optimal performance factors, and mitigate error evolution.

5 Conclusions

The systematic analysis of multiple video records of the same task at two or more levels of urgency was found to be revealing as a source of training material and performance improvement data. This method of targeted video task analysis may be generalisable to other brief, risky, but beneficial medical procedures such as those that may be carried out in the surgical, medical, critical care, pre-hospital and trauma resuscitation medical domains. It may also be applicable in non-medical domains.

References

Beishon RJ (1974) An analysis and simulation of an operator's behavior in controlling continuous baking ovens. In: Edwards E, Lees FP (eds) The human operator in process control. Taylor & Francis, London

Bainbridge L (1974) Analysis of verbal protocols from a process control task. In: Edwards E, Lee FP (eds) The human operator in process control. Taylor & Francis, London

Brown DL (1987) Trauma management: the anesthesiologist's role. Int Anesthesiol Clin 25:1–18

Caplan RA, Posner KL, Ward RJ, Cheyney FW (1990) Adverse respiratory events in anesthesia: a closed claims analysis. Anesthesiology 72:828–833

Cheyney FW, Posner KL, Caplan RA (1991) Adverse respiratory events infrequently leading to malpractice suits. Anesthesiology 75:932–932

Chipman SF, Schraagen JM, Shalin VL (2000) Introduction to cognitive task analysis. In: Schraagen JM et al (eds) Cognitive task analysis. Lawrence Erlbaum Associates, Mahwah, NJ, pp 3–23

Committee on Trauma, American College of Surgeons (1993) Advanced trauma life support: program for physicians. In: Crossman ER, Cooke JE (eds) Manual control of slow response systems: international conference on human factors in electronics. American College of Surgeons, Chicago

Gaba DM, DeAnda A (1988) A comprehensive anesthesia simulation environment: recreating the operating room for research and training. Anesthesiology 69:387–394

Harper BD, Mackenzie CF, Norman KL (1995) Quantitative measures in the ergonomic examination of the trauma resuscitation units anesthesia workspace. In: Proceedings of the 39th Annual Meeting of the Human Factors and Ergonomic Society, San Diego, CA, October 1995

Helmrich RL (1984) Cockpit management attitudes. Hum Factors 26:583–589

Howard SK, Gaba DM, Fish KJ, Yang G, Sanquist FH (1992) Anesthesia crisis resource management training. Teaching anesthesiologists to handle critical incidents. J Aviat Space Environ Med 63:763–770

Hoyt DB, Shackford SR, Fridland PH et al. (1988) Video recording trauma resuscitation: an effective teaching technique. J Trauma 28:435–440

Mackenzie CF, Xiao Y (2003) Video techniques and data compared with observation in emergency trauma care. Qual Saf Healthcare (12):ii 51–ii 57

Mackenzie CF, Craig GR, Parr MJ (1994) Video analysis of the emergency tracheal intubations identifies flawed decision-making. Anesthesiology 81:763–771

Mackenzie CF, Jeffries NJ, Hunter A et al (1996a) Comparison of self-reporting of deficiencies in airway management with video analysis of actual performance. Hum Factors 38:623–635

Mackenzie CF, Martin P, Xiao Y and the LOTAS Group (1996b) Video analysis of prolonged uncorrected esophageal intubation. Anesthesiology 84:494–503

Mackenzie CF, Xiao Y and the LOTAS group (1999) Video analysis for performance modeling in real environments: methods and lessons learnt. In: Proceedings of the 43rd Annual Meeting of the Human Factors and Ergonomics Society, Houston, TX, 27 September-1 October 1999

Mackenzie CF, Hu P-F, Hu F-M et al (2003a) Video acquisition and audio system network (VAASNET®) for analysis of workplace safety performance. Biomed Instrum Technol 37:285–291

Mackenzie CF, Hu FM et al. (2003b) Video acquisition and audio system network (VAASNET^R) for analysis of workplace safety performance. Biomed Instrum Technol 32:285–291

Moray N, Lootsteen P, Pajak J (1986) Acquisition of process control skills. IEEE Trans Syst M Cybern SMC-16:497–504

Xiao Y, Mackenzie CF (1997) Uncertainty in trauma patient resuscitation. In: Proceedings of the 41st Annual Meeting of the Human Factors and Ergonomics Society, Alburquerque, NM, September 1997

Xiao Y, Milgram P, Doyle DJ (1993) The classes of problem solving situations in managing complex systems. In: Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society, Seattle, WA, October 1993

Xiao Y, Mackenzie CF, and the LOTAS Group (1995) Decision-making in dynamic environments: fixation errors and their causes. In: Proceedings of the 39th Annual Meeting of the Human Factors and Ergonomic Society, San Diego, CA, October 1995

Xiao Y, Hunter WA, Mackenzie CF (1996) Task complexity in emergency medical care and its implications for team coordination. Hum Factors 38(4):636–645