**An Exploration of Cognitive Ergonomics in Neonatal Resuscitation**

By

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# Abstract

Each year 13-26 million infants worldwide will require neonatal resuscitation at birth. Care provided during neonatal resuscitation can range from suctioning the infant's airways and providing stimulation to endotracheal intubation and chest compressions. Healthcare providers (HCPs) must be able to evaluate the infant and provide appropriate interventions rapidly and effectively. However, human errors in neonatal resuscitation occur in 16-55% of cases. Most medical errors that result in poor patient outcomes are due to deficiencies in non-technical rather than technical skills. Non-technical skills involve the interpersonal and cognitive skills that underpin technical performance.

Several non-technical skills that have been examined in neonatal resuscitation include information gathering, situation awareness, decision making, communication, and teamwork. Many of the existing studies of non-technical performance in neonatal resuscitation examine these aspects independently of one another and take place in simulated settings. Cognitive task analysis is a group of methods used in the study of cognition in applied or naturalistic settings. These methods allow for the study of clinical practice as a social and situated task.

In this thesis, I examined the cognitive processes of a group of HCPs who acted as airway leads during neonatal resuscitation. I also characterized HCPs' perceptions of workload during neonatal resuscitation.

I recorded ten clinical neonatal resuscitations from the point-of-view of the HCP acting as the airway manager using mobile eye-tracking glasses. These glasses record the procedure from the point of view of the wearer and record where the wearer is looking by analyzing pupillary movements. Following the resuscitation, I asked the individual who wore the eye-tracking glasses to participate in a debriefing study and review the own-point-of-view eye-tracked recording of the resuscitation. While watching the video, HCPs were asked to "think aloud," verbalizing their thought

process throughout the resuscitation. The participants' retrospective think-alouds were paired with semi-structured interviews. The debriefing studies were audio-recorded, transcribed, and coded using thematic analysis.

Five overall themes were identified in the debriefings: situation awareness, performance, working in teams, addressing threats to performance, and perception of eye-tracking review.

During the debriefings, excess workload was identified as a potential threat to HCPs' performance. This relationship has been described in many clinical settings where excess workload has been associated with delays, errors, and negative effects on the healthcare team, such as fatigue, stress, and illness. Therefore, our second project aimed to characterize workload experienced by HCPs who participate in neonatal resuscitation. In this project, we also examined the effect that parental presence during resuscitation had on HCP experience of workload to address concerns that parents' presence may contribute to HCP workload and therefore compromise care.

Perceived workload was measured using a multi-dimensional retrospective National Aeronautics and Space Administration Task Load Index (NASA TLX) survey. The NASA TLX collects data on six dimensions: mental, physical, and temporal demand, performance, effort, and frustration. Each dimension is rated independently by participants on a scale of 0-20 (0 being lowest and 20 being highest). The Raw-TLX score is a composite score of all dimensions and is presented on a scale of 0-100. HCPs completed a paper and pencil survey after attending delivery room resuscitations over a three-month period. A total of 204 surveys were completed. The overall median (interquartile range) Raw-TLX was 34(18-49). The scores varied by dimension. Overall workload of neonatal HCPs was higher during resuscitation of infants with lower 5-minute Apgar scores and those who required more invasive procedures. Overall workload of HCPs was significantly lower when at least one parent was present compared to when no parent(s) were present during the resuscitation.

These studies were limited in their scope and size, but they demonstrate the feasibility of two novel methods in this setting. The study of HCP non-technical performance may inform policy, equipment design, team assignment, and training in neonatal resuscitation. Ultimately this may improve the safety of neonatal resuscitation.

# Preface

This thesis is an original work by Emily Caroline Zehnder. This thesis consists of two research projects which have received research ethics approval from the University of Alberta Research Ethics Board including i) Analysis of Visual Attention and Team Communications during Neonatal Resuscitations in the Delivery Room Using Eye-Tracking: an Observational Study, Pro00077581 and ii) Subjective Workload of Healthcare Professionals who Participate in Neonatal Resuscitation, Pro00090092.

Projects in this thesis were completed in collaboration with our research team. Chapter 1 includes a modified version of a review published in Frontiers in Pediatrics (Volume 7) as "An opportunity for cognitive task analysis in neonatal resuscitation" (doi:10.3389/fped.2019.00356). I wrote the first draft of this review and edited all consecutive drafts with feedback from Dr. Law and Dr. Schmölzer.

Chapter 2 describes the methods for data collection and analysis of both the studies in Chapters 3 and 4. These were developed by myself, along with Dr. Law and Dr. Schmölzer. Chapter 2 includes a modified version of a paper published in SAGE Research Methods Cases: Medicine and Health as "Eye-tracking video augmented cognitive task analysis of neonatal resuscitation" (doi:10.4135/9781529734478). This paper was drafted by Dr. Schmölzer and myself.

In Chapter 3, Dr. Law and Dr. Schmölzer assisted with conceptualizing the project. Caroline Fray, Sylvia van Os, and Dr. Law assisted with data collection. Dr. Law assisted with data analysis. Dr. van Manen provided expertise on qualitative data analysis and provided feedback on an earlier version of results.

In Chapter 4, Dr. Law and Dr. Schmölzer assisted with conceptualizing the project. A version of Chapter 4 is currently under peer review. Caroline Fray, Sylvia van Os, Dr. Law, and Dr. Schmölzer

assisted with data collection. Dr. Schmölzer assisted with data analysis. Dr. Law and Dr. Schmölzer performed manuscript edits.

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## Abbreviations

| | |
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| ANOVA | - Analysis of variance |
| CPAP | - Continuous positive airway pressure |
| CTA | - Cognitive Task Analysis |
| DST | - Decision support tool |
| EDA | - Electrodermal activity |
| HCP | - Health care professional |
| ICU | - Intensive care unit |
| IQR | - Interquartile range |
| NASA TLX | - National Aeronautics and Space Administration's Task Load Index |
| RN | - Registered nurse |
| NICU | - Neonatal intensive care unit |
| NRP | - Neonatal Resuscitation Program |
| PPV | - Positive pressure ventilation |
| Raw TLX | - Raw task load Index score |
| RT | - Respiratory therapist |
| SA | - Situation awareness |
| SME | - Subject matter expert |
| SD | - Standard deviation |
| V | - Video |

# Chapter 1. Introduction

This chapter consists of slightly modified sections from a previously published article and has been reproduced here with the permission of the copyright holders: Zehnder E, Law B, Schmölzer GM. An opportunity for Cognitive Task Analysis in neonatal resuscitation. *Front Pediatr* 2019;7:356. doi:10.3389/FPED.2019.00356

## 1.1 Neonatal Resuscitation

Neonatal resuscitation is the set of interventions performed at birth to support the establishment of circulation and breathing. Approximately 10%  of infants will require some form of resuscitation at birth, and 1% will need more extensive resuscitation, such as endotracheal intubation or chest compresson[1]. Globally, this equates to 13-26 million infants each year. Rapid and appropriate interventions at birth are critical as delays or errors in care can result in life long cognitive and motor deficiencies or mortality[2–4].  Increasingly, the performance of the healthcare team has been identified as an area of improvement in neonatal resuscitation[5]. This follows the Joint Commission 2004 Sentinel Event Alert, which identified human failures as the root cause of over two-thirds of morbidity and mortality associated with neonatal resuscitation[4].

Ideally, neonatal resuscitation is performed by a team of well-trained health care professionals (HCPs) who have strong cognitive, psychomotor, and communication skills. This team must rapidly process various dynamic pieces of information to assess the infant's condition, determine appropriate interventions, and execute these actions efficiently and effectively.  Given these demands, it is not surprising that human errors or protocol deviations frequently occur during neonatal resuscitation. Error rates have been reported to be between 15 and 55% during simulated and clinical neonatal resuscitations[6,7]. An analysis of errors during clinical neonatal resuscitations found that error rates were higher during resuscitations that were more complex or required more interventions. The authors of this paper speculated that high cognitive and technical workload might be to blame for the increased error rates[8].

## 1.2 Cognitive Task Analysis

Cognitive Task Analysis (CTA) is a set of methods used to identify task demands, and cognitive skills needed to complete a task. These methods belong to the field of cognitive ergonomics, a discipline focused on the evaluation of human cognition as it relates to tasks, environments and systems. CTA is often used to capture expertise; by breaking down complex cognitive processes that drive a set of behaviours and can be used to formulate comprehensive algorithmic descriptions of tasks and define task rules[9,10]. CTA is a diverse group of methods; more than 100 different systematic and scientific CTA have been described[11]. While specific elements of each CTA approach differ, common steps include: 1) collection of preliminary knowledge, 2) identification of knowledge representations, 3) application of focused knowledge elicitation methods, 4) analysis and verification of data acquired, and 5) formulation of results for intended applications[10]. CTA can be used to examine cognitive, psychomotor, and communication processes that may inform interventions aimed to improve HCPs' communication, education and the environment in which they work. Below I have described some of the ways CTA methods have been applied in healthcare.

### 1.2.1 Medical Equipment

During neonatal resuscitation, equipment must be reliable, user-friendly, and allow for easy detection of equipment flaws. Malfunctioning of equipment or user-interface issues could result in increased stress and cognitive load in HCPs, which might result in detrimental effects on patient outcomes. CTA could be used to assess i) HCPs' interaction with medical technology, ii) preferences and difficulties, and iii) how to recognize and cope with equipment failure.

Recently Applied CTA was used in the development of a heart rate recording device for neonatal resuscitation[12]. In this project, product designers ran an Applied CTA and traditional user-centred design approach with a group of neonatal HCPs. Applied CTA is a streamlined method of CTA used to assess the cognitive requirements of a task and present findings in an operational manner, often for system designers[13]. The addition of an Applied CTA in this project allowed for an understanding of the cognitive requirements, and the potential for error during heart rate monitoring in neonatal resuscitation. Some factors that were identified in this study as being difficult for neonatal HCPs included the judgement of accuracy and reliability of heart rate display and reliance on previous experience and recognition of "normal" heart rate and chest movement to inform decisions and actions. Some potential errors were failure to recall normal heart rate and chest movement, and overreliance on technology (lacking reliability) and colleagues' earlier assessment. Authors claimed that this methodology revealed new user requirements and was informative in the design of the clinical interface[12].

CTA has also been used to assess vital sign monitors and incubators[14,15]. Li *et al* assessed how neonatal HCPs retrieve data on vital sign monitors and identified several challenges, including overwhelming alarm noises and difficulties assessing unusual events[14]. This led to the development of automated aids for cardio-respiratory trend retrieval and alarm limits adjustment[14]. Similarly, Ferris *et al* developed blueprints of incubator systems based on CTA assessment that would better fit the needs of infants, parents, and HCPs[15]**.** CTA identified several flaws, including i) confusing alarm information, ii) ambiguous commands with scale functions, iii) unintuitive icon displays, and iv) lack of variability in alarms with existing incubator systems, and provided solutions[15]. These examples demonstrate various ways through which CTA has already been and can continue to be used to improve neonatal resuscitation equipment for HCP use.

### 1.2.2 Clinical Decision Support Tools

Decision support tools (DSTs) are designed to decrease the cognitive load of HCPs, improve quality of care, and decrease human errors by linking health observations with health knowledge. Though many DSTs are electronic, any tools, designs or systems, which link health observations to health knowledge may be considered a DST. DSTs cover a portion of the cognitive load previously allocated to an HCP, freeing up cognitive resources for other tasks[16]. This is important as excess cognitive load has been associated with human error [17]. DSTs have been developed for use in neonatal resuscitation, including visual and auditory reminders to prompt interventions (i.e., the ringing of the Apgar-timer at 1, 5, and 10 min). Fuerch *et al* assessed the impact of a visual and auditory DST. They reported significantly improved mask ventilation performance (94-95% vs. 55-

80% in intervention vs. control group, p<0.0001) and chest compressions (82-93% vs. 71-81% in intervention vs. control group, p<0.0001) during simulated neonatal resuscitations[18].

Similarly, Schnittker *et al* designed a DST for use during challenging airway management in adult anesthesia[19]. Critical Decision Method interviews and focus groups with HCPs identified that the location of airway equipment was the main contributor to successful airway management[19,20]. Critical Decision Method is a form of CTA during which a participant is asked to describe a previous non-routine challenging experience and recalls decisions made and actions taken[21]. Based on this assessment, Schnittker *et al* customized an airway equipment trolley with a strategic layout and set-up to support decision making in anesthesia [20]. This approach was decided on as anesthesia team members are thought to act through a recognition-primed process that links cues and actions; the equipment was positioned to make these cues more salient to aid in the recognition and decision making[19,20].

Despite the benefits of DSTs, the acceptance rate is often low[22]. Several barriers are preventing routine use of DST, including perceived clinical irrelevance and discordance between cognitive processes and user interface[22]. CTA may be used to overcome these barriers for DST to be integrated into clinical practice. In 2005, the Fuzzy LOgic REspiratory Neonatal Care Expert DST was developed to support HCPs in their decisions to change the settings on a ventilator in infants with respiratory distress syndrome[23]. To ensure successful acceptance and integration of FLORENCE into clinical practice, three CTA based knowledge elicitation methods - content analysis, Critical Decision Method, and observation - were used[23]. Similarly, CTA methods, including Cognitive Walkthrough and think-aloud, were used to assess the interaction of neonatal HCPs with an antibiotic-prescribing DST[24]. Both the Cognitive Walkthrough and think-aloud are methods that involve HCPs expressing their train of thought during task completion. Cognitive Walkthrough aims to simulate a user's thought process as they interact with an interface[25]. Think-aloud has a subject matter expert (SME) verbalizing their thought process while completing a task[26]. These methods identified several human-computer interface problems, including lack of screen cues and ambiguous icons, which were associated with excessive cognitive efforts[24]. These CTA approaches could also be used to optimize the design of DST for neonatal resuscitation.

### 1.2.3 Teamwork and Communication

During resuscitation, HCPs are reliant on team communication and a shared mental model, which serves as an exchange of patient information, education, coordination, and quality assurance. Ineffective communication can result in wasted resources, frustration, and errors, putting patients at risk[27]. CTA can be used to better understand the dynamics of team communication and how their effectiveness could be improved. The benefits of CTA in analyzing team performance include understanding how teams i) interpret situations and make joint decisions, ii) monitor team communication, and iii) overcome confusion[9]. An improved understanding of cognitive processes involved in team communication during a neonatal resuscitation might guide the development of training and information systems to optimize team communication and performance during resuscitations.

McHugh *et al* used Critical Decision Method in combination with direct observation to characterize communication among a multi-disciplinary critical care team[28]. McHugh *et al* interviewed team members individually and identified i) barriers (e.g., fragmentary teams, role ambiguity, external collaborators, and novice difficulty in transitioning to from tactical to strategic) and ii) facilitators (e.g., collaborative rounds, daily goal forms, and collaborative construction), which were used to develop a shared understanding and multi-disciplinary collaboration[28]. Similarly, CTA-based interviews with HCPs in a pediatric intensive care unit identified the teams' cognitive framework in complex pediatric patient care [29]. The interviews suggested that the care teams' efforts to create a shared mental model for their patients was central to the long-term care plan of patients across shift changes and hand-overs[29]. Schraagen *et al* used observation-based CTA to assess team performance in a pediatric cardiac surgery care team and compared them to surgical outcomes[30]. A total of 255 hours of operations were observed with a 76% inter-rater agreement and a 91% inter-rater reliability of the four main teamwork categories[30]. Also, CTA has been successfully used to coach effective teamwork through simulation design[31]. These studies suggest that CTA might be an alternative approach to assess team performance and knowledge retention during neonatal resuscitations as well as an effective mechanism to optimize team behaviours.

**1.2.4 Training**

CTA can be used to promote knowledge transfer from experts to non-experts. By breaking down complex automated skills into bite-sized pieces, CTA could provide more accurate and thorough teaching. When experts describe protocols or procedures to novice learners, they fail to describe an estimated 70% of the analytical and critical decisions required to complete the task[32]. These omissions are thought to be the experts' experiential knowledge, which is predominantly unconscious[32]. CTA forces experts to consider the knowledge they use to complete a task, and in turn, make this information available to learners[33]. In an assessment of education provided by surgical experts, CTA-prompted training resulted in an average of 22% more steps being described over unprompted teaching [33].

*Benefits of CTA-Based Training*

CTA-based instruction has been associated with an average increase of 30-45% in learning (depending on CTA methods used) when compared to traditional task analysis methods [34]. Furthermore, a meta-analysis of CTA-based instruction reported large effect size (Hedges's $g$=0.871)[35]. Also, CTA-based education in surgery reported improved educational and surgical outcomes (e.g., including time, precision, and accuracy) and fewer errors compared to traditional learning methods[36].

However, the evidence of CTA-based medical education to train neonatal HCPs is limited. Crandall *et al* used Critical Decision Method interviews with expert Neonatal intensive care unit

(NICU) nurses to identify clinical symptoms for early sepsis detection[37]. Overall, 36% of cues used by NICU nurses to correctly diagnose early sepsis were not reported in the medical literature or training materials. These novel cues (e.g., "sick eyes," poor muscle tone, edema) were subsequently added to training material and textbooks for future nursing students[37]. Similarly, Critical Decision Method interviews with NICU nurses were used to identify indicators for necrotizing enterocolitis (e.g., context-specific lethargy, colour changes, increased apneas), which were then shared with learners[38]. Critical Decision Method interviews with expert HCPs who perform neonatal resuscitation might reveal details previously overlooked or not thought of. This might be crucial information to improve learners' knowledge and improve outcomes for newborn infants.

*Expert-Novice Differences*

Using CTA, different approaches could be optimized to teach a task to experts and novice learners [39]. Patterson *et al* used Critical Decision Method interviews to understand the differences between expert and novice HCPs in their recognition of sepsis in pediatric patients. They reported that experts described more hypothesis testing and violated expectations compared to novice HCPs[39]. These results were then used to develop an educational tool to train novice HCPs[39].

*Simulation-based Training*

Simulations encourage experimental learning through the artificial representation of real scenarios to allow theoretical knowledge to be translated into clinical skills. This method does not put patients at risk and is independent of case availability. The benefits of simulation training in neonatal resuscitation include enhanced technical, behavioural and cognitive skills as well as team performance, and self-confidence[40]. Regardless of the learning method, skills are lost over time, which might be countered with periodic simulation training[41]. CTA could be used to develop training scenarios, performance metrics, and identify training needs and simulator requirements, which might result in a higher mental representation of learners during a simulation[42,43]

Cannon-Bowers *et al* developed a five-step guide for simulation design using CTA: i) select relevant SME, ii) elicit major tasks and subtasks through think-aloud, iii) have SME complete tasks using probing to elicit critical cues iv) ask questions related to simulation deficiencies, and v) elicit errors more likely made by novice learners[42]. Munro *et al* used a multistage CTA, called Concepts, Processes, and Principles, to elicit medical, instructional, and software expertise and integrate this into simulation design[34]. During Concepts, Processes and Principles, SMEs are asked to create a gold standard list of steps involved in the completion of a task then describe critical concepts, processes, or principles that need to be learned to explain and perform each step[34]. More recently, Pander *et al* incorporated CTA into the design of team-based simulations using three main steps i) definition of all steps of a simulation procedure, ii) identification of intra-operative technical and non-technical skills required by all involved professionals, and iii) analysis of results[44]. Patterson *et al* used another approach involving CTA during the content and structure design of the simulations, which were then story-boarded[45]. The resultant simulation was perceived as relevant and useful by learners (>70% of learners scored usefulness of simulation as >7/10)[45].

Applied CTA has been used to assess the impact of simulation training in pediatric extracorporeal cardiopulmonary resuscitation and reveal targets for further training[46]. This method exposed two behaviours (coordination of compression with surgical cannulation and performance of sterile compressions), which were targeted for further simulation training[46].

CTA during the design or improvement of neonatal resuscitation simulations could follow any of the methods described above. CTA could be used to determine the content and structure of scenarios, develop these training scenarios, and develop performance metrics based on the scenarios developed.

### 1.2.5 Assessment

CTA-based assessments can be used to evaluate technical and non-technical skills in a clinical setting. Non-technical skills (i.e., communication, leadership, and situational awareness) are core competencies in clinical practice[47,48]. During neonatal resuscitations, these skills are particularly important as they have been identified as causes of human error[4,7,49].

While no study has used CTA to assess non-technical skills during neonatal resuscitation, these methods have been successfully used in other medical disciplines, including surgery and anesthesiology [50–52]. The Anesthetists' Non-Technical Skills assessment tool, for example, was developed using CTA and has since been validated with high inter-rater reliability in both a clinical and simulated environment[53]. Anesthetists' Non-Technical Skills assessment tool has since been used in neonatal resuscitation[54]. Szulewski *et al* performed a CTA of residents who completed simulation-based emergency room resuscitation exams. This approach allowed for qualitative characterization of the cognitive processes underlying resident's crisis resource management and an examination of how these skills varied with the resident's performance[55]. This information could be applied to improve the non-technical assessment of residents performing simulation-based resuscitation.

Similarly, CTA has been used to assess surgical technical skills during simulations[56], scenario testing[57], and checklists[58], which are part of new surgical performance metrics. Recently, a surgical competency assessment tool to assess technical and non-technical components of transurethral resection of a bladder tumour using CTA was developed with reported feasibility, validity ($r>0.5$, $p< 0.01$), and reliability (coefficient Phi $\geq 0.8$)[59]. The method used to create these tools could be adapted to assess technical and non-technical skills during neonatal resuscitation.

### 1.2.6 Opportunities for the Application of Cognitive Task Analysis to Neonatal Resuscitation

CTA could be applied to many aspects of neonatal resuscitation. Specifically, CTA could be used to improve resuscitation equipment, design clinical decision support tools, assess teamwork and communication, and inform the development of training and assessment tools. As neonatal resuscitation is largely guided by standardized algorithms, CTA could also be used to study causes of algorithm deviations, analyze how algorithm adherence differs between experts and novices, and identify when experts might decide to deviate from the algorithm in a given clinical context.

CTA could also be used to study the integration of advanced monitoring equipment into neonatal resuscitation. In addition to the electrocardiogram and pulse oximetry currently recommended by international guidelines, additional monitoring, including near cerebral infrared spectroscope and respiratory function monitoring, are being investigated in the context of neonatal resuscitation.  CTA could be used to examine how HCPs integrate the additional information provided by these monitors into established clinical decision pathways. This information could be used to design monitor displays to provide information in a manner that best fits the pre-existing cognitive framework of HCPs, thus optimizing usability while minimizing additional cognitive demands. CTA could also be used to guide the design of a DST.

Neonatal resuscitation presents unique challenges to the application of CTA methods. Given the fast-paced and demanding nature of neonatal resuscitation, it may not be feasible to use CTA methods that occur during actual resuscitations (e.g., think-aloud), as this may increase the cognitive burden and compromise clinical performance. Instead, CTA methods that must be performed during task completion could be performed during simulated neonatal resuscitation. Alternatively, videos taken during resuscitations could be used to prompt recall. Mobile eye-tracking glasses have been used to analyze the visual attention of HCPs during neonatal resuscitation[60]. These glasses use reflected infrared light to track pupillary movements while simultaneously recording video from the wearer's viewpoint. The resulting video indicates the wearer's visual focus during the performance of clinical tasks (e.g., what they were looking at when performing bag-mask ventilation). Thus, eye-tracking recordings can be used to provide an information-rich prompt for the recall of knowledge, cognitive tasks and decision-making after an actual neonatal resuscitation event.

Given the diverse physical and social environments in which neonatal resuscitation occurs and the variety of HCP roles required to complete this task, it is unlikely that the cognitive pathways exposed using CTA in one context will be generalizable to all settings. For example, knowledge elicited from an HCP practicing in a tertiary care center may not be generalizable to an HCP practicing in a low-resource setting. Similarly, SME from different disciplines (physician, nursing, respiratory therapy, midwifery, etc.) may offer significantly different perspectives despite applying the same CTA methods in the same clinical context. CTA that examines neonatal resuscitation across settings and roles is therefore needed to accurately inform improvements to neonatal resuscitation equipment, DST, teamwork, and training.

## 1.3 Workload

Workload is an important aspect of cognitive ergonomics. Cognitive ergonomics research and applications often aim to manage or decrease workload of a task[61]. The term "workload" refers to the cost to a human operator of completing a task. Workload is affected by not only the objective requirements of the task but also by the environment in which the task is performed. The abilities, behaviours, and perceptions of the operator are also a crucial consideration[62]. Humans are limited in their ability to identify, consider, and act on information efficiently and accurately. Therefore, if the workload of a task becomes too great, delays and errors become more likely, and human costs such as fatigue, stress, and illness may reach an unacceptable level[63,64]. Excessively low workload, referred to as underload, can also contribute to performance detriments due to reduced alertness and lowered attention [65].

In many instances, deterioration in performance due to inappropriate workload can be counteracted by the investment of strategic resources[66,67]. Understanding how workload is experienced by individuals and teams can guide strategic resource allocation and may, therefore, guide interventions aimed at improving performance.

### 1.3.1 Workload and Medical Errors

Considering work hour restrictions, technological changes, and a distracting environment, HCPs experience high levels of workload. Exceeding optimal workload limits can hinder HCP performance and compromise patient safety. This is demonstrated via a relationship between staffing levels in a health care institution and patient outcomes[68,69]. A positive association between workload and iatrogenic complications (complications not associated with the patients' underlying disease) as measured via HCP self-report, has also been demonstrated[70].

The association between workload and likelihood for patient harm has more recently been supported among neonatal HCPs. Excess workload was the most frequently cited cause of almost-adverse events (reported in 49% of almost adverse event cases) in an evaluation of adverse medical events and almost-adverse events in a NICU[71]. Almost adverse events refer to errors that did not result in severe outcomes or were corrected before a severe outcome could occur[71]. Furthermore, in an assessment of workload experienced by neonatal nurses, the high workload was associated with increased incidences of missed nursing care. Each 5% increase in nurse’s subjective rating of workload was associated with a 34% increase in the likelihood of missed care for their assigned infant during the corresponding shift [63]. In a high stake, fast-paced setting such as neonatal resuscitation, a high baseline workload requirement means that few cognitive resources are available to identify and act on unexpected complications. This risk may be compounded by the low rate of occurrence with which high acuity resuscitation takes place in some settings.

### 1.3.2 Measures of Workload

Workload cannot be measured directly but can be quantified using objective task requirements, secondary task performance, physiological measures, and subjective rating scales. In the health care setting, workload is often quantified using an objective measure such as the number of beds per HCP[72], patient to HCP ratio, patient to provider ratio with a weighting scale of patient acuity[73], and specific to nurses, the number of non-nursing tasks including patient transport and housekeeping tasks[74]. These measures are beneficial as they can be readily observed retrospectively but are limited as they do not account for situational or individual factors that contribute to workload.

Secondary task performance has also been applied as a measure of workload. This method is more frequently used in experimental, simulated, or low-risk settings as it involves participants engaging in a task that is secondary to the primary task in which workload is being measured simultaneously. Poorer performance on the secondary task suggests that more cognitive effort is required to complete the primary task[75]. Secondary task performance has limited applicability as a measure of workload in health care as this may compromise patient safety.

Physiological measures of workload often rely on neurovisceral integration or the structural link between cognitive regulation and physiological processes. Some of these measures require invasive testing or specialized equipment, thus limiting their use to experimental settings (e.g., blood draws, functional magnetic resonance imaging, positron emission tomography). In contrast, others can be measured via non-invasive wearable monitors, which are more appropriate for simulation settings and, in some instances, the clinical environment though often resource-intensive.

Cardiac activity as measured via heart rate, inter-beat intervals, and heart rate variability have all been used as measures of workload. In general, heart rate tends to increase with task difficulty[76], the number of tasks required[77] and the addition of memory load[78]. However, more complex measures of heart rate have also been developed to measure workload. An example is the division of the low frequency and high-frequency bands of heart rate variability, which correspond to sympathetic activation and parasympathetic activation, respectively [79]. Sympathetic predominance is an indication of increased workload, and therefore increased workload is associated with a higher low-frequency/high-frequency ratio[79]. Various measures of cardiac activity have been applied as measures of workload in surgical settings[80–82].

Pupillometry is the study of changes in pupil size associated with cognitive processing. This measure has been examined in several experimental tasks, including memory tasks[83], arithmetic tasks[84], digit span task[85], and visual search task[86]. The pupil's response to mental load is known to be tightly associated with activation of the locus coeruleus[87]. The locus coeruleus is the sole modulator of the noradrenergic system within the brain. Locus coeruleus-noradrenergic system plays an important role in various functions that contribute to cognitive workload, including selective attention and memory retrieval[88]. Pupil dilation is most commonly measured using either a pupillometer or eye-tracking glasses. In the past, the cost and complexity of these tools limited their use, particularly in an applied setting, but these barriers to use have been lessened with the development of more affordable and simpler to use eye-tracking technology. Over the past several decades, pupillometry has been applied in a variety of simulated and applied clinical settings[89–91] For example, Zheng *et al* assessed changes in pupil size throughout a simulated surgical procedure and found that pupil responses were not only affected by task difficulty of the current task but also affected by subtasks directly before and after[92]. Furthermore, Brunye *et al* found that the pupil size of pathologists was influenced by the difficulty of image interpretation and agreement with consensus diagnosis[90].

In both experimental and applied tasks, increased difficulty is associated with increased pupil dilation. In some experiments, dilation reaches a plateau at a certain task difficulty or even decreases above a certain level of difficulty[85,93]. This feature may limit the usefulness of pupil diameter as a measure of workload in applied medical settings as the cognitive demand placed on HCPs is often consistently very high. Another limitation of pupillometry as a measure of workload is that the reliability of this measure seems to decrease in older populations[94] and in less intelligent individuals[95]. Additionally, ambient lighting, the distance of visual attention, and caffeine or nicotine consumption may alter results[96].

Electrodermal activity (EDA), also called galvanic skin response, is another measure that has been used as a proxy for workload. EDA is a measure of the skin's conductivity. The skin, in contrast to other body systems, is innervated by only the sympathetic nervous system and is not under the control of the parasympathetic nervous system. Sympathetic activation leads to the production of sweat. EDA takes advantage of this characteristic and measures sympathetic activation by measuring skin conductance, which is proportional to sweat secretion. EDA is most often measured using a constant voltage system in which two electrodes are applied to human skin, and a very weak voltage is running through the electrodes to measure skin conductance. EDA measures resistance across fingers, head, feet, back, or wrist. Measurement of EDA on one's wrist is minimally invasive and monitoring equipment can be worn around the wrist like a watch. EDA has been used as a measure of workload in experimental tasks[97] and clinical settings[98,99].

Phitayakorn *et al* assessed the practicality of using EDA measures in operating room team members. They concluded that EDA is feasible in a simulated operating room but may be difficult to implement in an actual operating room due to logistical difficulties and associated confounds[98]. Berguer *et al* assessed cognitive demands on surgeons in open surgery compared to laparoscopic surgery using various physiological and subjective measures of workload, including EDA. In their analysis, EDA was associated tightly with other measures[99]. While the majority of the literature seems to suggest increased cognitive workload is associated with increased EDA, some studies have found no relationship between cognitive workload and EDA, while others have found that EDA increases with decreased cognitive demand[100]. Some proposed explanations for these discrepancies include differences in sensitivity of  EDA assessment tools, and simple tasks being more tedious than the difficult tasks[100].

### 1.3.3 Subjective Measures of Workload

Subjective rating scales, in comparison to physiological rating scales, may require fewer resources. Numerous subjective workload rating scales have been developed. In these assessments, operators are asked to assign a value to their experience of workload following task completion. These measures are often referred to as offline measures as they provide one overall rating of workload for the entire task or portion of the task assessed. Physiological measures or secondary task performance may be measured during task completion and therefore reflect changes in workload that occur as the task is being completed. These are referred to as online measures. Subjective rating scales rely on the assumption that operators can accurately reflect on and rate their experience of workload quantitatively. Gopher and Braune supported this assumption in their work, demonstrating that people are competent at assigning numerical values to their perceived mental effort[101]

Some of the more widely applied subjective workload rating scales include i) Modified Cooper-Harper Scale, a 10-point unidimensional scale paired with a decision tree to guide the rater in determining the correct rating[102], ii) Overall Workload, a unidimensional scale of 0 to 100 representing very low to very high workload respectively[103], iii) Subjective Workload Assessment Technique, a multidimensional scale considering time load, mental effort, and psychological stress each rated on three levels: low, medium, and high, then transformed into a score out of 100[104], and iv) NASA TLX, a multidimensional scale considering mental demand, physical demand, temporal demand, performance, effort, and frustration, each rated on a 100 point scale in which 0 is lowest (or best in the case of performance) and 100 being highest (or worst in the case of performance)[62].

*NASA TLX*

Following a three-year development cycle and over 40 simulation trials, the Human Performance Group at NASA's Ames Research Center released the current version of the NASA TLX[62]. This tool has since been used in a variety of domains, including aviation, nuclear power plant control rooms, sport and health care[105]. NASA TLX can be administered as a paper and pencil survey or as an official computerized implementation.

## 1.4 Parents' Presence During Neonatal Resuscitation

Many factors may affect HCPs' workload during neonatal resuscitation; one factor is the presence of the infant's parent. Parents often prefer being present during neonatal resuscitation and benefit from this experience[106,107]. However, the effect that parental presence has on the healthcare team during neonatal resuscitation is not well characterized. Concerns about parents' presence affecting HCPs' stress and performance during neonatal resuscitation have been reported by both parents who have witnessed the resuscitation of their child and neonatal HCPs[106,108]. Parental presence may affect the objective demands of HCPs (e.g., HCPs may need to comfort parents while performing resuscitation), the physical setting (e.g., more HCPs around the infant might result in less working space), and the circumstances surrounding the resuscitation (e.g., communication style between HCPs).

## 1.5 Purpose Statement

In this thesis, I explored aspects of cognitive ergonomics in neonatal resuscitation through two methods not previously applied in this setting.

*Study Objectives and Hypothesis*

The objectives of the first study described in Chapter 3 were to i) describe the cognitive processes of a group of HCPs who act as airway leads during neonatal resuscitation and ii) determine the feasibility of own-point-of-view eye-tracked video as a prompt for retrospective think-aloud in neonatal resuscitation. I hypothesized that the method would be feasible in this setting and would provide insights into HCP cognition.

The objectives of the second study described in Chapter 4 were to i) characterize HCPs' perceived workload during neonatal resuscitation ii) determine if parental presence during neonatal resuscitation affects the perceived workload of HCPs. I hypothesized that HCPs' overall workload would be greater in higher acuity events compared to lower acuity events and in resuscitations during which parents were present compared to no parents present.

# Chapter 2. Methods

This chapter consists of modified sections from a previously published article and has been reproduced here with the permission of the copyright holders: Zehnder E, Schmölzer G. Eye-Tracking video augmented cognitive task analysis of neonatal resuscitation. SAGE Res Methods Cases. March 2020. doi:10.4135/9781529734478

## 2.1 Cognitive Task Analysis To Explore Healthcare Professionals' Cognitive Processes During Neonatal Resuscitation

### 2.1.1 Study Design Overview

This study was comprised of three phases: i) collecting of own-point of view, eye-tracked, audiovisual recording of clinical neonatal resuscitation, ii) reviewing and debriefing recording with the HCP participant, whose point of view was reflected in the recorded resuscitation, through a retrospective think-aloud and semi-structured interview, ii) transcribing, debriefing, and analyzing transcripts.

### 2.1.2 Study Setting

This study took place at the NICU at the Royal Alexandra Hospital, Edmonton, Canada. This hospital is a tertiary perinatal center admitting approximately 350 infants with a birth weight of <1500g to the NICU annually. Deliveries are attended by the resuscitation-stabilization-triage team. Depending on the delivery indication, the team members might vary, but typical for our institution is attendance by i) a neonatal nurse and neonatal transport nurse alone for infants >32 weeks' gestation; ii) a neonatal nurse, neonatal transport nurse, neonatal respiratory therapist, and neonatal nurse practitioner and/or a neonatal fellow for infants <32 weeks' gestation. The number of people who attend a resuscitation also varies by availability and other situational factors. This setting proved an ideal location for our study, as neonatal resuscitations occur frequently. Therefore, it was possible to record more resuscitations than would have been possible in a center with fewer high-risk deliveries. Recordings took place in the resuscitation room adjacent to the delivery room, where infants were brought immediately following cord clamping. Resuscitation rooms, which were separate from the delivery room, were beneficial for our study as they protected the privacy of the mother who was giving birth. The debriefings took place in a private office located near the NICU.

### 2.1.3 Study Participants

Given the frequency, unpredictability, and often urgency with which neonatal resuscitations occur, it was not feasible for our research team to record every resuscitation. Therefore, we had to narrow our inclusion criteria. We included a convenient sample of resuscitations that occurred during the workweek or when a member of our research team was available outside of this window. We attended deliveries of infants who were deemed to have a high likelihood of requiring a more complex resuscitation as these cases would provide richer data for our study. These included infants born less than 34 weeks of gestation or infants who had a known abnormality that may have impacted their cardio-respiratory function at birth. Around 400 of these infants are born at this hospital each year.

HCPs who acted as the airway lead (or at the head of the bed) during resuscitations were eligible to participate. HCPs were not excluded based on professional designation; however, individuals who take on this role at our institution tend to be neonatologists, neonatal fellows, neonatal nurse practitioners, neonatal transport nurses, or respiratory therapists. All eligible HCPs are certified according to the Neonatal Resuscitation Program 7$^{th}$ Edition[109].

### 2.1.4 Sample Size Consideration

We aimed to continue with recordings and debriefings until a significant repetition of ideas and concepts across cases was identified, which would suggest a saturation point. By limiting recordings to resuscitations that were anticipated to be more demanding or complex as a result of prematurity or congenital abnormality, information-rich cases were targeted. Therefore, that anticipated number of cases required was smaller. Though significant repetition of concepts was identified in our analysis, data collection was limited by pragmatic considerations. HCPs who participated in the eye-tracked recording portion of this project were generally keen to participate in the debriefing. Still, it was often difficult to arrange a meeting time as meetings were arranged during the HCPs' clinical shift. HCPs were often busy with unpredictable work during their shift and were therefore not available to meet.

**2.1.5 Recordings**

When informed of an impending neonatal resuscitation, a member of our research team would deliver eye-tracking equipment to the resuscitation, stabilization, and triage room attached to the delivery room. In this room, the HCP who would be acting as the head of the bed (also called airway manager) was identified and briefly told about our study and the recording capabilities of the eye-tracking glasses. These HCPs (one per resuscitation) were then asked if they would like to participate in our study. HCPs who verbally agreed to participate (verbally consented) were fitted with mobile eye-tracking glasses (Tobii Glasses, Tobii Technology, Inc., Falls Church, VA). The glasses were then calibrated according to the manufacturer's instructions. Once calibration was completed, HCPs continued to prepare for the resuscitation as usual. We attempted to minimize demands placed on participants during this point in our method as they were busy preparing for the arrival of the infant. Typically, our brief conversation, glasses fitting, and calibration took around one minute to complete. The HCP who wore the glasses was told that they were welcome to take off the glasses at any point if they felt that the glasses were uncomfortable or impeding their clinical practice. No HCPs removed the glasses during resuscitation in this study. The HCP then completed the resuscitation as they typically would. Once the resuscitation came to a natural end (the infant was prepared to travel to the NICU, or the infant was stable and procedures that were not a part of the initial resuscitation commenced), the recording was ended. Glasses were collected from the HCP. At this point, written consent was collected from the HCP, and they were asked if they would be willing to complete a debriefing study while reviewing the recording. The participant was also allowed to withdraw from the study, in which case the video recording would be deleted.

*Recording using Eye-tracking Glasses*

Resuscitations and participants' visual attention were recorded using head-mounted eye-tracking glasses (Tobii Glasses, Tobii Technology, Inc, Falls Church, Virginia) (Figure 2.1). These glasses reflect near-infrared light to track reflection patterns on the cornea and pupil of the eye. Image processing algorithms then generate estimates of eye-position and point of gaze. Gaze patterns are marked on an own-point-of-view recording taken by a camera positioned on the front of the glasses. The product is an audiovisual recording showing what was "seen" by the participant along with a gaze marker demonstrating the precise visual attention. These glasses have been used previously in neonatal resuscitation and other clinical settings where they have not impacted clinical care provided by the wearer[110–112].

**Figure 2.1** Eye-tracking glasses worn by HCPs while performing neonatal resuscitation

### 2.1.6 Debriefing

The debriefing portion of this study involved a think-aloud by HCP participants prompted by eye-tracked own-point-of-view recordings and a semi-structured interview.

*Think-aloud*

The think-aloud method is a participant-driven CTA technique that typically occurs during task completion[26]. This approach has the participant speak freely about all thought processes (e.g., perceptions, predictions, judgments, decisions) that take place during a procedure or task. This method is based on Ericsson and Simons' protocol analysis and was later described in the field of cognitive ergonomics[26,113,114].

Participants who perform concurrent think-alouds during the completion of complex tasks tend to be less successful at task completion and may share incomplete verbalizations[115,116]. While performing neonatal resuscitation, HCPs must be attentive to their role, communicate with one and other clearly, and make decisions quickly. A concurrent think-aloud may impede these roles and is therefore not feasible in a clinical (as opposed to simulated) neonatal resuscitation.

Alternatives to a concurrent method in a clinical setting include a think-aloud during a simulated procedure or a retrospective think-aloud method. With each of these alternatives comes a set of drawbacks. HCPs' thought processes during a simulation may differ from a clinical resuscitation. Further, concurrent think-alouds are, in some cases, affected by reactivity as the act of speaking throughout the simulation may distort the decision making under investigation[117]. Concurrent think-alouds rely on participants' ability to share what is taking place in their working memory explicitly. For this to be done, participants must vocalize their cognitions within a very specific window of time. If this time frame is missed, vocalizations are no longer an accurate representation of working memory[118]. In team-based tasks, like neonatal resuscitation, in which HCPs must communicate verbally with their colleagues, think-aloud verbalizations may be delayed and, therefore, less accurate[118]. Retrospective reports do not rely on this level of stringency as they rely largely on the contents of the long-term memory[118]. Retrospective think-alouds are limited by the participant's memory and are affected by interpretations by participants and potentially fabrications of mental events[119,120].

In their description of verbal reports, Erickson and Simon categorized verbalizations into three types: i) type one verbalizations refer to concurrent verbal reporting while problem-solving ii) type two refers to delayed verbalizations after problem-solving has occurred iii) type three refer to elaborations, introspections, or explanations[121]. While concurrent think-alouds are largely made up of type one verbalizations, retrospective think-alouds will likely consist of a higher proportion of type two and three verbalizations.

*Eye-tracked Own-Point-of View Recordings to Augment Retrospective Think-Aloud.*

To assist with participant recall, video recordings have been used successfully to prompt retrospective think-alouds in many settings, including marketing research, sports and medicine[112,122,123]. Own-point-of-view eye-tracked video recordings are often used as they provide a representation that more closely reflects participants' experience of a task compared to a traditional video recording[112,124,125]. Using an own-point-of view recording may allow for greater psychological immersion than an external camera as they show details of what was the focus of participants' attention during task completion. These recordings promote a form of recall referred to as reminiscence[126]. Reminiscence is the act of recollecting or re-living past experiences or events and is thought to support the sharing of emotional experiences[126]. Additionally, traditional video recordings which have participants view their behaviours from an external perspective may lead the participants to analyze their actions and critique their decision rather than recalling elements which affected their reasoning[127].

Eger *et al* completed an assessment of eye-movement tracked recordings paired with retrospective think-aloud in the study of human-computer interaction. They demonstrated that retrospective think-aloud cued by eye-movement data resulted in a greater quantity of verbalization and more insight than conventional or concurrent think-aloud[128]. Retrospective think-alouds cued by eye-movements are also thought to be less reactive than concurrent think-alouds as participants were less likely to successfully complete the assigned task when thinking aloud concurrently versus retrospectively[128].

*Suitability of a Video Cued Think-aloud to Examine the Cognitive Processes of HCP in Neonatal Resuscitation*

Think-alouds are only able to reveal thoughts that are accessible in the conscious mind; therefore, automatic processes cannot be effectively assessed. It is recommended that this method is not well suited for simple or repetitive tasks (which tend to be largely automated)[129]. On the other hand, Ericsson and Simon described that demanding tasks might create cognitive interference with verbalization as processing required to complete the task may crowd working memory[114]. This threat is likely not as relevant to the retrospective think-aloud as participants will not need to complete the task while speaking aloud.

Seagull and Xiao assessed the feasibility and benefit of eye-tracked recording to augment CTA. They suggested that tasks that are visually intensive, time-pressured with high decision density, involve monitoring or information gathering and require individual performance are better suited for assessment using eye-tracking techniques. In contrast, tasks that rely primarily on audio-based or recall rather than visual content, are slow-paced or have low decision frequency, which do not require information gathering or are team-based are less well suited[130]. Apart from the team-based nature of resuscitation, the tasks required of an airway lead in neonatal resuscitation meet the characteristics established above. Though HCPs work closely as a team in this task, their visual attention is mostly focused on the infant and monitoring equipment[60].

*Method in Practice*

The debriefing portion of this study took place at a convenient time for the participant as soon as possible following the recorded resuscitation. When participants arrived, informed consent was collected, participants' initial questions were answered. I assured participants that I had no training in neonatal resuscitation and was in no way judging or assessing their verbalizations during the debriefing or their performance in the recordings which we would be reviewing. They were told that we were interested in a detailed unedited recollection of their thought processes during preparation and involvement in a resuscitation. It was important that participants' stress or anxiety was minimized during the debrief, as anxiety resulting from the evaluative function is thought to lead to self-monitoring, which can affect the accuracy of think-aloud results. Leighton demonstrated that the accuracy of verbal response process data is positively influenced by the identification of the interviewer as a non-expert in the field[131].

Participants were taught how to interpret the eye-tracked recording (i.e., the circle moving around the screen is where your eyes were focused at that point in the resuscitation) and how to pause and play the recording. The interviewer then gave participants a more detailed explanation of the task. Participants were asked to think back to the resuscitation and try to verbalize what was "running through their heads" as they prepared for and participated in the recorded resuscitation. We asked them to share as much detail as possible and to not be concerned about their phrasing as they spoke. Participants were encouraged to pause the recording to complete a thought at any point.

We aimed to record the preparations for resuscitation in our eye-tracked recordings. However, sometimes this preparation ended long before the arrival of the infant. In these cases, there was a long period of the recording (5-15 minutes) which was comprised of HCP waiting (no longer actively preparing) and discussing topics not related to the resuscitation or engaged in some other activity not related to the resuscitation. In these cases, we marked down these points in the recording and skipped past them during the think-aloud to respect our participants' time.

Once participants' questions had been answered, I began recording with a Dictaphone and played the video recording with the volume on. There was variation in how much each participant verbalized. Some paused the video frequently to finish a thought before letting the video continue, while others would let 20 – 30 seconds pass before speaking. When long periods occurred without any verbalization, the interviewer would prompt comments with cues such as "what were you thinking about here?" or "I see you were looking at the monitor for a while here." Probing during think-aloud is thought to support completeness, but it may influence participants' verbalization[132].

*Interview*

During the debriefing portion of this study, think-aloud was paired with a semi-structured interview with participants. Throughout the interview, the recording was paused at set points, and questions pertaining to the most recent portion of the recording were asked (e.g., once the preparation was complete immediately before the arrival of the infant or once the infant was transitioned to a ventilation device). Questions asked during the paused points in the video were clarifying in nature and inquired about actions in the recording that the participant had not discussed spontaneously during the think-aloud. Following the completion of the recording, several semi-structured interview questions were asked. These allowed participants to reflect more generally on their performance during the recorded resuscitation and their experience reviewing the own-point-of-view eye-tracked recording. The interview and video data allowed us to analyze the data and to expand on think-aloud results [129]. Furthermore, including follow-up interview questions provided participants with the opportunity to confirm the researcher's interpretation of their initial verbalizations[129].

The interview guide was generated through consultation with experts in neonatal resuscitation, the Neonatal Resuscitation textbook 7th edition[109], observation of clinical resuscitations, and reviewing video recorded neonatal resuscitations. It highlighted common points in the resuscitation and areas of clinical variance, as well as listing potential clarifying questions for each of these points.

**2.1.7 Analysis**

Transcripts of the debriefing portion of this study were subjected to a thematic analysis[133]. This analysis was conducted primarily by me, with support from Dr. Brenda Law, a neonatologist with experience conducting human factors research, who reviewed all transcripts. While I have described the “phases” below in a linear manner, our analysis was reiterative as I moved back and forth between phases frequently.

Thematic Analysis, as described by Braun and Clarke, involves six phases[133]. The first phase is becoming familiar with the data. In our study, this was done through transcription of the debriefing studies along with repeated re-reading of the transcripts and review of eye-tracked recording corresponding to the transcript for context. I transcribed debriefing studies verbatim including comments on the content of eye-tracked video referenced by participants when necessary (e.g., participant stated “this is lower than I anticipated” when referring to heart rate reading displayed on the monitor). Transcriptions of the debriefing studies were uploaded to the Nvivo software (Version 12, QSR International) for analysis. Phase two is generating initial codes. I began generating codes by assigning labels to sections of transcripts. Several initial codes were taken from the literature on non-technical performance in neonatal resuscitation and from cognitive ergonomics literature, but most emerged during analysis of the transcripts. Phase three is searching for themes within the codes, which I did by considering common ideas behind the codes and grouping them accordingly. Phase four involves a review of the themes identified in phase three. I completed this by re-examining transcripts and determining if themes seemed to fit across cases. At this point, I met with

Brenda Law to discuss codes and proposed themes, as well as the relationships between various codes. Following this, I returned to phase three and added some new codes and combined and eliminated some themes while adding others. I reviewed the updated themes by re-examining transcripts and met with Brenda Law again to compare and discuss updated themes and codes until consensus was met. Together, we began phase five. Phase five was defining and naming themes; this involved discussion of the meaning of each theme, which was later summarized in writing. Finally, phase six involved the production of a report (Chapter 3). Here, I aimed to describe the themes identified and participants' recollection of their cognition supported with examples from the transcripts. Square brackets represent sections of quotes that have been edited and ellipses represent omission of words within a quote.

### 2.1.8 Trustworthiness

Some qualitative researchers suggest when examining the rigour of a qualitative study that reliability, validity, and generalizability may not be the most appropriate measures or concepts[134]. Instead, Guba and Lincoln suggest that the trustworthiness of a project should be examined, including the concepts of credibility, dependability, confirmability, and transferability[135].

Credibility is akin to internal validity and questions whether the researcher accurately represents the participants' ideas or viewpoints[136]. To support the credibility of my work, I clarified HCPs' remarks made during think-alouds in a semi-structured interview and provided HCPs with the opportunity to expand on their remarks. Further, I considered and reviewed the recorded resuscitation while analyzing HCPs' think-aloud remarks. This provided context and clarified uncertainties. Throughout this project, I had prolonged and varied engagement within the setting of neonatal resuscitation, which allowed me to better understand the contextual meaning of HCPs' remarks. I watched over 20 recorded neonatal resuscitations within the institution before beginning the project. While watching some of these recordings, a neonatologist explained the common steps of neonatal resuscitation. I reviewed the relevant literature and observed simulated and clinical resuscitations. I was able to ask questions and engage with HCPs immediately before and after resuscitations. These measures helped me to become familiar with the steps of neonatal resuscitation and with the culture of the institution.

Dependability is akin to reliability and asks if similar results would be obtained if the project were to be repeated in the same context with the same participants and the same methods[136]. Similarly, confirmability is the confidence that the results can be confirmed or corroborated by other researchers[136]. I included a detailed description of data collection and analysis in this chapter to support dependability and confirmability. I also included many direct quotes from participants in Chapter 3 of this thesis to support my descriptions of HCP cognition. Further, I kept a record of our collected data in the form of i) audio recordings and transcription of debriefings, ii) audio-visual recordings of cases, iii) a case report form for each recorded case iii) various iterations of codes and themes generated in this project.

Transferability is akin to generalizability and refers to the extent to which findings can be transferred to other settings[136]. I do not suggest that the themes from this study will apply directly to all settings in which neonatal resuscitation takes place. Generalization of these themes to other settings and cases must be mindful of the education, professional designation, and experience of HCPs who participated in this project along with the resources available and culture of HCPs within the institution. I have thoroughly described the study population and setting to allow readers to determine if the themes derived from this project can be applied to their population of interest.

### 2.1.9 Ethical Considerations

The Royal Alexandra Hospital Research Committee and the Health Ethics Research Board, University of Alberta (Pro00077581), approved this study. We worked with the Human Research Ethics Board at the University of Alberta to develop a protocol that allowed for written consent to be obtained retrospectively from HCPs who participated in our study. This was necessary as neonatal resuscitation is a medical emergency and often gives HCPs little time to prepare for the arrival of a patient. Consenting HCPs at this point could further limit their time to prepare for the procedure and could, therefore, compromise patient safety. Though we did not obtain written consent from participants until after the procedure, we ensured that participants understood what the glasses would record and that their participation was completely voluntary. Following the procedure, when eye-tracking glasses were removed from participants, written consent was obtained, and participants were told that their recording could be deleted and removed from our research anytime until the publication of our results. A separate consenting procedure was done directly before the debriefing.

Ethical dilemmas associated with the recording and review of neonatal resuscitations have been described previously[137,138]. They include questions such as: Should parents consent? Who is the research subject - the HCP or the newborn? Is the de-identification of the recordings mandatory? Can the impact of the technique deteriorate received care? [137,138]. In this project, we worked with the Health Ethics Research Board, University of Alberta, to navigate these questions and ensure that potential risks were minimized.

## 2.2 Subjective Assessment of Healthcare Professionals' Workload During Neonatal Resuscitation

### 2.2.1 Study Design Overview

In this study, HCPs completed surveys that measured subjective workload following their participation in delivery room care.

### 2.2.2 Study Setting

This study took place at the NICU at Royal Alexandra Hospital, Edmonton, Canada. The Royal Alexandra Hospital Research Committee and the Health Ethics Research Board, University of Alberta (Pro00090092), approved this study. Participants were recruited through the Health Ethics Research

Board-approved study posters, which were displayed throughout the NICU and the delivery rooms for the duration of the study period. Participation was voluntary, and consent was implied by survey submission.

**2.2.3 Study Participants**

All neonatal HCPs who attend high-risk deliveries were eligible to complete a survey. Every HCP was asked to complete one survey each time they attended a delivery regardless of their role, profession, level of training, or which interventions were performed at the delivery.

**2.2.4 Sample Size Consideration**

As this was the first use of the NASA TLX tool in the delivery room, we were unable to estimate effect size. Therefore, we chose to use a convenient sample of 200 survey responses for this study, based on a review of the literature[139,140,141].

**2.2.5 Survey Overview and Distribution**

The paper and pencil survey used in this study included a NASA TLX workload assessment tool, and collected demographic data about respondents, the patient and the procedure corresponding to the survey. Participants were asked to provide us with examples of aspects of the resuscitation, which contributed to their experience of various components of workload to get a better idea of respondents' understanding of questions and prompts (Table 4.3). The survey is attached at the end of this chapter.

This was an anonymous pencil and paper survey, which took approximately 10 minutes to complete. Participants were asked to complete a survey immediately after delivery by taking a survey from a marked folder within the NICU. Once completed, surveys were placed into a secure letterbox and collected by the research team.

### 2.2.6 Demographic Information

Information about survey respondents, and about the procedure they recently completed was collected. HCPs-related information included profession, years of experience, and gender. Procedural information included the role in resuscitation, time of day delivery took place, interventions performed during resuscitation, notification time before delivery, the number of team members involved, and parental presence. Patient data included birth weight, Apgar score, sex and mode of delivery.

### 2.2.7 NASA TLX Tool

NASA TLX is a subjective post-hoc measure of workload. NASA TLX independently assesses six dimensions: 1) mental demand, which refers to how much mental or perceptual activity was required to complete the task, 2) physical demand, referring to the amount of physical activity required to complete the task, 3) temporal demand, referring to how much time pressure was experienced when completing the task, 4) performance, referring to the respondent's perception of how successful they were in completing their role in the task, 5) effort, which refers to the level of mental and physical exertion required to accomplish the level of performance achieved during the task, and 6) frustration, which refers to how insecure, discouraged, irritated, stressed, or annoyed respondent was during the task. The domains "mental, physical, and temporal demand" relate to the demands imposed on the participant, whereas performance, effort, and frustration focus on the interaction of the subject with the task. Each dimension is rated on a 20-step scale from "very low" to "very high," except performance, which is rated from "perfect" to "failure." No numerical values were present on the survey scales. Handwritten markings were translated to values (0-20) corresponding to the nearest step mark on the survey. To gain a better understanding of each HCP's perception of these dimensions, descriptions of factors that either contributed positively or negatively to their experience of workload were collected.

### 2.2.8 Analysis

The median (IQR) score of each of the six workload dimensions considered in the NASA TLX were calculated. Overall workload is represented as Raw-TLX, which was calculated for each survey response as the mean of all dimension scores multiplied by five to transform this score to a value out of 100. The Raw-TLX scores were compared using a non-parametric Wilcox rank-sum test and Analysis of Variance (ANOVA) with Bonferroni post-test. The Raw-TLX score was compared by the HCP role and by the 5-minute Apgar Scores. The 5-minute Apgar score was divided into three groups according to Neonatal Encephalopathy and Neurologic Outcomes,2nd Edition (7-10 - high Apgar score group; 4-6 - medium Apgar score group; 0-3 - low Apgar score group)[142]. The Raw-TLX scores were compared by parental presence. This comparison was made across all survey responses and within 5-minute Apgar groups. The data are presented as mean (standard deviation, SD) for normally distributed continuous variables and median (interquartile range, IQR) when the distribution was skewed. P-values are 2-sided, and $p<0.05$ was considered significant. Statistical analyses were performed with Stata (Intercooled 12, Statacorp, Texas).

*Weighting*

The NASA TLX contains a weighting component in which the relative importance of each dimension of workload in the completion of a task is determined via a set of paired comparisons completed by each respondent[62,105]. The relative importance is considered in a weighting scheme during calculations of the overall workload score[62,105]. Though the weighting component of the NASA TLX may increase sensitivity to relevant variables and decreases inter-rater variability relative to an unweighted score[105], our analysis was completed using the unweighted Raw-TLX. This portion of the study was left blank on 32 of returned surveys (15.7%). These omissions may be due to participant confusion or limited time. The weighted and unweighted overall workload scores are consistently correlated[143,144]. Young and Stanton have suggested that this implies that the weighting procedure is superfluous and is not necessary[145].

### 2.2.9 Quality of NASA TLX as a Measure of Workload

Various factors have been considered to identify a good measurement of workload. These measures are summarized below.

- Validity is the tool's discriminatory ability to detect changes in workload and not some other factor. Validity can be further divided into convergent validity and concurrent validity. Convergent validity measures how closely the values measured by one tool correlate to another tool assumed to measure the same concept. Concurrent validity is the tendency of a tool to predict outcomes of another tool that is assumed to measure the same construct. Rubio *et al* assessed the convergent validity of NASA TLX by calculating the Pearson correlation coefficients between overall workload scores of NASA TLX & Subjective Workload Assessment Technique (0.9817) and NASA TLX & Workload Profile (0.9863). They concluded that the tool's convergent validity was very high[146]. To measure the concurrent validity of NASA TLX, Rubio *et al* computed the Pearson correlation coefficients between Raw TLX and performance measures in an experimental setting. Compared to the other tools, NASA TLX correlated most closely to the performance matrix assessed in the task and was therefore considered to have the greatest concurrent validity[146]. The convergent validity of NASA TLX in intensive care nurses has also been supported as is highly correlated with Rating Scale Mental Effort (r=0.77), and the Perceived Workload Scale (r=0.81) in a secondary analysis on NASA TLX surveys collected from 757 ICU nurses in 21 ICUs. The authors of this study concluded that NASA TLX is a reliable and valid tool for measuring workload in ICU nurses [147].
- Reliability reflects the tool's consistency in reporting of workload. Evidence suggests that NASA TLX is a reliable tool for use in intensive care settings (Cronbach's alpha = 0.72) [146]. In an assessment of the reliability of NASA TLX in 1068 mental workers from a variety of

occupations including administration, education, research, and healthcare, Cronbach's alpha coefficients were more than 0.80 [148].

- Intrusiveness is the tool's propensity to interfere with the primary task. As NASA TLX is completed following task completion, it can be assumed that the intrusiveness of this tool is negligible.
- Implementation requirements consider the logistical or resource needs for the tool to collect and assess workload. NASA TLX is available as a phone-based app, computer software, and paper and pencil survey. Therefore, the requirements to use this tool are minimal and can be adapted depending on the context of use.
- Diagnosticity is the tool's ability to identify the reason(s) for variation in workload. NASA TLX creates a workload profile associated with each measure of the overall workload. This workload profile demonstrates the relative contribution of each dimension of workload and may help researchers identify reasons for variation. A stepwise discriminant analysis performed by Rubio *et al* demonstrated the ability of NASA TLX workload profile to discriminate between single and dual tasks (when participants were doing one task at a time vs. both) but not between single tasks so there may be limitations to NASA TLX's diagnosticity[146].

In summary, the reliability and validity of NASA TLX as a measure of workload has been supported in many populations and tasks, including certain healthcare settings such as the Adult Intensive Care Unit. No attempt to validate NASA TLX as a measure of workload experienced by HCPs participating in neonatal resuscitation has been performed.

Questioner and NASA TLX Assessment

**Title: Subjective Workload of Healthcare Professionals Who Participate in Neonatal Resuscitation**

**What is your profession?**

| | | | | | | |
|---|---|---|---|---|---|---|
| RN | TN | NNP | RT | R1-4 | Fellow | Neo |

**What was your role in this resuscitation?**

| | | | | | |
|---|---|---|---|---|---|
| Team Leader | Airway manager | RN | RT | Recorder | Observer |

**Gender:** Mr. / Ms. / Mx.

**How many years of experience do you have in the NICU? ________**Yrs.

**Note time of day when resuscitation occurred to the nearest hour only __________** AM / PM

**How long did you have to prepare for the resuscitation relative to the birth of the baby?**

| | | | | | |
|---|---|---|---|---|---|
| Code Pink | Arrived After Baby | 0-5 min | 5-10 min | 10-20 min | 20+ min |

**Which interventions were performed during this resuscitation?**

| | | | | | | |
|---|---|---|---|---|---|---|
| Stimulate | Suction | CPAP | PPV | Intubation | Chest Compression | Epinephrine |

**How many team members were involved in this resuscitation?___________**

**Do you think anything about this resuscitation could be improved on in the future?**

______________________________________________________________________

**Were the babies parents present at any point during the resuscitation? Yes / No**

**Note the gestational age and weight of the baby: ________Weeks __________Grams**

**Apgar: 1min _____ 5min______ 10min______**

**Sex: Male / Female**

**Mode of Delivery: Vaginal / Instrumental / C/S**

**NASA-Task Load Index**
Please mark an "X" on each of the below scales rating your experience of the resuscitation you just participated in. Consider each scale independently.

**Note this table is just for your reference as you complete the scales below

**Main Contributor** (Circle one and provide example)

| | | | |
|---|---|---|---|
| Patient Factors | Equipment Factors | Team Factors | Personal Factors |

Example:________________________________________

**Main Contributor** (Circle one and provide example)

**Main Contributor** (Circle one and provide example)

| | | | |
|---|---|---|---|
| Patient Factors | Equipment Factors | Team Factors | Personal Factors |

Example:________________________________________

**Main Contributor** (Circle one and provide example)

| | | | |
|---|---|---|---|
| Patient Factors | Equipment Factors | Team Factors | Personal Factors |

Example:________________________________________

**Main Contributor** (Circle one and provide example)

| | | | |
|---|---|---|---|
| Patient Factors | Equipment Factors | Team Factors | Personal Factors |

Example:________________________________________

**Main Contributor** (Circle one and provide example)

| | | | |
|---|---|---|---|
| Patient Factors | Equipment Factors | Team Factors | Personal Factors |

Example:________________________________________

**Main Contributor** (Circle one and provide example)

| | | | |
|---|---|---|---|
| Patient Factors | Equipment Factors | Team Factors | Personal Factors |

Example:____________________________________________

**Source of Workload Evaluation**
Circle the factor on the left or right in each pair which was more important to your experience of workload during this resuscitation:

**For example**, if you felt that physical demand played a larger role in your experience of workload than temporal demand and performance was more important than physical demand a portion of your response would look like:

Please circle one choice in each row:

| | | |
|---|---|---|
| Frustration | Vs. | Effort |
| Performance | Vs. | Mental Demand |
| Performance | Vs. | Temporal Demand |
| Mental Demand | Vs. | Effort |
| Mental Demand | Vs. | Physical Demand |
| Effort | Vs. | Physical Demand |
| Frustration | Vs. | Mental Demand |
| Effort | Vs. | Performance |
| Temporal Demand | Vs. | Frustration |
| Temporal Demand | Vs. | Effort |
| Physical Demand | Vs. | Frustration |
| Performance | Vs. | Frustration |
| Physical Demand | Vs. | Temporal Demand |
| Physical Demand | Vs. | Performance |
| Temporal Demand | Vs. | Mental Demand |

# Chapter 3. Cognitive Task Analysis to Explore Healthcare Professionals' Cognitive Processes during Neonatal Resuscitation

## Overview

Most medical errors that result in poor patient outcomes are due to deficiencies in non-technical rather than technical skills[149]. Non-technical skills involve the interpersonal and cognitive skills that underpin technical skills. Further, the context in which HCPs act significantly influences their decision making and cognition[150]. Therefore, the demands and constraints of a situation must be considered when examining clinical non-technical performance. The study of HCP performance and the cognitive processes underpinning performance in neonatal resuscitation is difficult in part due to the fast-paced and high-risk nature of the procedure. Simulation studies have been used to examine both technical and non-technical behaviours in neonatal resuscitation successfully. Though this is undoubtedly a valuable tool in the study of human performance during clinical procedures, it is important to consider that the behaviours displayed by participants in simulation studies may not directly reflect those that occur in clinical settings[151]. Audio-visual recording review has been applied successfully in many clinical settings to examine the cognitive processes of HCPs as they complete clinical tasks[152,153]. Further, own point-of-view recording may support recall, and eye-tracking layover may add specificity to recall [112].

This project aimed to i) assess the feasibility of eye-tracked, own-point-of-view video augmented CTA as a means of studying cognitive processes of HCPs in neonatal resuscitation and ii) describe the cognitive processes that occur during neonatal resuscitation, as described by HCP participants.

## Results

Eight HCPs participated in this study. Two of these HCPs participated twice for two separate resuscitations. Therefore 10 cases were included in this study. A summary of participant information and corresponding procedural data is presented in Table 3.1. Overall, five themes emerged; these were situation awareness, performance, working in teams, addressing threats to performance, and perception of eye-tracking review (Figure 3.1).

## 3.1 Situation Awareness

Participants described a conscious awareness of the resuscitation situation, in keeping with the concept of situation awareness. Elements of this awareness included perception of stimuli, situation monitoring, comprehension, or making sense of the situation and projection of anticipated outcomes.

### 3.1.1 Perception of Stimuli

HCP participants described their perceptions as composed of a combination of auditory, visual, and tactile stimuli. The sources of stimuli were most often the i) patient (e.g., "she was also a little bit pale," or "baby is crying; you can hear her being very gurgly"), ii) team members (e.g., "based on her fingers I can tell the rate that she's tapping it's [heart rate] somewhere between 90 and 110"), and iii) monitoring equipment (e.g., "the alarm started to go and he was 79 (% oxygen saturation)."). The density of stimuli available during the recorded resuscitations was apparent through not only the participant's recollection of their perceptions but also through reviews of the eye-tracked video.

### 3.1.2 Situation Monitoring

HCP reported using both a top-down and bottom-up approach to develop and maintain an understanding of the resuscitation. HCPs discussed purposely monitoring the situation during resuscitation. Descriptions of monitoring included phrases such as scanning or looking across to multiple perceptual stimuli within the resuscitation environment to maintain a current understanding of the patient's status. Participants described quickly and repeatedly gathering information from multiple sources to guide their current awareness of the situation and, therefore, their clinical decision making. For example, one HCP reported "I will sort of follow the same sort of circuit in my vision and be like monitor, monitor, monitor time, check baby and try to go through all of the little pieces to make sure that things are OK and if nothing has changed then cycling back around and being like OK, anything different here? No. Anything different here? (Video 4 (V4))" In contrast to the top-down approaches described above in which HCP seek out information in their environment, participants also described moments when a cue or other event drew their focused attention away from the situation as a whole to monitor specific stimuli suggesting bottom-up processing. For example, an alarm indicating low oxygen saturation caused one HCP to focus their attention on the monitor and away from the baby.

Participants described both stimuli that they were reflectively aware of and unreflectively aware of during the resuscitations. Some stimuli of unreflective awareness were evident to participants when they reviewed the eye-tracked recording: For example, one participant was trying to assess her patient's status shortly after birth when she commented: "I am looking very quickly at this monitor. I'm not sure that I can even see the numbers (V2)."  When referencing stimuli they had been reflectively aware of during the resuscitation, HCPs remembered noting and reflecting on the stimuli in the resuscitation room. Furthermore, participants emphasized being reflectively aware of critical stimuli while unreflectively disregarding other information (without necessarily deliberately thinking about it) that was less critical to the resuscitation. For example, a participant stated, "I am not worried about our heart rate and saturation because she looked fairly well aside from having these intermittent apneas (V3)." While acknowledging she attended to the heart rate and saturation values, this participant emphasized focusing her attention on the infant's physical appearance.

### 3.1.3 Comprehension

HCPs described making sense of the resuscitation situation by relying on their pre-existing knowledge. HCPs referenced a standard or expected value for the infant's vital signs to comprehend the infant's condition. These reference values were from their memory: "That [saturation] is lower than the target range (V6)," or from visual aids: "I am just looking at the age of the baby, comparing to my saturation and the temperature as well. She is [at] 40% oxygen [saturation], but within the 10 minutes, so I was just checking that with my chart (V2)."

Additionally, HCPs noted changes in an infant's status over time using their earlier impressions as a reference. These changes were apparent through infants' i) vital signs: "We are hovering in the low 90's - 100's for heart rate and then there was a brief improvement and then here we started slowing (V5)," ii) physical appearance: "He is still quite cyanotic, but there is a slight improvement centrally (V6)," and iii) infant's activity level: "she was starting to make some spontaneous movements (V2)." Frequently these perceived changes in the infant's status were associated with a recent intervention, allowing for assessment of their response to intervention. For example, "It seems the tactile stimulation is not enough to maintain the drive to breathe (V6)," or "Her breathing seems improved with a shoulder roll in place (V6)." By assessing how an infant's status changed with interventions, HCPs described making sense of whether an intervention was working or not. For example: "You can see that his heart rate is a little bit lower than it had been so something was off with the seal or my breaths or something (V1)" and "Whenever we change the position to extend the neck further to open up the airway to see if the heart rate goes up so when doing that I saw that the heart rate was going down so I had to go back to a neutral position so we might have been hyperextending her head (V9)."

### 3.1.4 Projection

HCPs described not only relying on their current understanding of the situation to guide their clinical decision making but also on their anticipations of how the infant would progress in response to resuscitation. These anticipations were informed by HCPs' perceptions and comprehension, along with their knowledge and experience. In this quote for example: “Because if the baby is not getting good tidal volumes, then eventually the heart rate is going to fall and the saturations will fall (V4),” the HCP described perceiving the infant’s tidal volume then evaluating the meaning associated with these values before anticipating how the patient will progress. Likewise, many HCPs quickly made judgments about the level of care an infant will require very quickly after birth. For example, one HCP described watching as the obstetrics team surgically extracted their patient: “If the baby’s head has been stuck for quite some time and the baby is breech and it's a difficult extraction then the baby can be a little bit flatter at birth and take more time to resuscitate. So, may need some more support.” This HCP then described how she may use this history to inform her decision making during the resuscitation: “It can speed along what I'm trying to or intend to do. So, I may not give the baby as much of a chance to start breathing spontaneously, so if the baby is not breathing or is apnoeic, then I may intervene quicker than if it was born without any extraction issues (V2)”.  Some HCPs waited until they were able to see the infant for themselves to anticipate the level of care which would be required: “If you see them tucked and flexed, it is a good sign that this is going to be okay, obviously really loud crying is one of the most reassuring signs that a baby is transitioning well and should need minimum resuscitation, so those are the first two indicators where I am like OK, this is going to be good I should not have to provide this baby with too much (V3).” HCPs also described comparing the infant’s status to how they had anticipated the infant would progress at an earlier point in the resuscitation. For example, “I'm looking at the baby; I'm seeing peripheral and central cyanosis;

generally, I'm expecting this to improve really quickly - certainly more so centrally - it's not improving as much as I would like (V6)."

## 3.2 Performance

HCPs described evaluative aspects to their actions in the resuscitations in keeping with the concept of performance. Elements of performance included compliance with guidelines and protocols, clinical experiences, and team member actions.

### 3.2.1 Compliance with Guidelines and Protocols

HCPs described relying on resuscitation guidelines (neonatal resuscitation program algorithm (NRP) and hospital-specific adaptations) to guide their individual and group actions. Specifically, HCPs described guidelines as orienting the resuscitation team to a shared starting point and step-through process of resuscitation. I have described this further in the "working in teams" theme (section 3.3.4). Further, HCPs described how their knowledge of resuscitation guidelines affected their anticipations, decision making, and performance. Some HCPs described mentally reviewing the NRP steps prior to the infant's arrival as was exemplified in this HCP's reflections: "what is going through my head is … ok baby is going to come stim, suction, heart rate, PPV [positive pressure ventilation], monitors you are just going through the same thing. What is the order that I want to go through these? If I do not have heart rate, then I will do PPV then I am going to do 10-15 breaths, then readjust. Next things then readjust constantly just back and forth. Also, if I need to intubate who is my back up, what size tube do I need, where does the baby need to go to and those sorts of things and I will just go through that ad nauseum until something catches my eye or attention (V4)." Similarly, another HCP described guidelines directing the first few moments of their resuscitation: "We've been taking the steps of NRP, so the drying and stimulating. You are always assessing visually what your baby is doing and how they are responding (V2)." Additionally, in the following example the HCP described how their knowledge of resuscitation guidelines informed their decision making: “if this was a term baby with this sort of activity level meaning the baby is frantically moving his arms and legs, has really good tone, is already starting to pink, and crying vigorously we would not have even started CPAP [continuous positive airway pressure]. But guidelines and knowing that we were 32 weeks [gestation], I knew the baby would benefit from CPAP, so we made that decision (V3).”

When discussing what they may do differently than a more novice provider, one HCP commented that “we increase the [fraction of inspired oxygen] before [the arrival of the infant] for a baby that is little and a novice would not do that as it is not part of NRP (V7).” This comment suggests that in some cases, intentional deviation from protocol may be seen as a sign of experience rather than as a failure in performance.

### 3.2.2 Accord with Clinical Experience

In addition to their understanding of guidelines and protocols, HCPs evaluated their actions based on their clinical judgements. They discussed how they prioritized elements of care, effectively problem-solved when challenges arose, and optimized the use of the material and team resources. For example, one HCP described why they had not yet started to look up at the monitor: “Because I've been to so many other deliveries, I know that it has not yet started to pick up [heart rate and saturation readings]; it takes a bit of time (V3).” They described how they used their experience to optimize their attentional resources. HCPs described using their clinical judgement to prioritize interventions: “From past experience, the babies typically do better once they are on the [CPAP machine] so my thought process at this point which I did not verbalize, but I probably should have, was that if we get her on the [CPAP machine], she may actually improve, so instead of us having to give her PPV, she may maintain her own breathing better than what she can with the T-piece (V3).” Finally, another example is one HCP using practical clinical experience to troubleshoot an equipment issue before it posed a real challenge to the resuscitation: “We have the probe on but sometimes we need to hold it a little bit or this posey helps to get a better reading (V10).”

### 3.2.3 Comparing to Team Members

Some HCPs described comparing their actions to team members. This valuation of their own performance also reflected an effort to learn from one another. For example, one HCP described: "A lot of the stuff that I do I've modelled off of people who have more experience than me (V6)." Another HCP described actively trying to learn from their colleague while attending a resuscitation where the patient required an intervention that the participant infrequently performs on their own. "I am monitoring vital signs and watching her do this procedure so that I can know. I do this on occasion as well, but it has been a while since I have done this, so I want to watch how she is doing it (V5)." In a different case, the HCP reported learning about a different method of organizing twin deliveries: "I feel like something that some people do is label the warmers 'A' and 'B,' because even though you talk about it, inevitably someone will ask me and they do not know so that is something I can probably do next time. It does seem a little bit extra to do it, but inevitably, you have to spend time telling people where to go (V1)."

## 3.3 Working in Teams

HCPs described resuscitations as a team practice characterized by team dynamics reflecting trust and familiarity, role-taking, information sharing, and mutual support.

### 3.3.1 Trust and Familiarity

Several HCPs commented on the dynamic of the teams they were working in and how this dynamic affected individual and team performance. The familiarity of team members in the recorded resuscitations was often mentioned. HCPs described being confident in and trusting of team members because of their familiarity. For example, one HCP noted while reflecting on the team's preparation for a complex resuscitation: "We are a team that is very used to working together, and I think that you can see this… we have all practiced a lot and have been to many, many deliveries together, so everybody knows what to anticipate (V3)". In a different example, one HCP described relying on their assistant to monitor the infant's status without having to explicitly state this because they were very familiar with each other's expectations: "I did not specifically state it [ask the assistant to alert if status fell below an acceptable level]… because we are so used to working together, I feel as though it is implied (V3)." Further, during a twin delivery, when twins were delivered to the opposite teams than was planned, one HCP reflected: "I was not too panicked because I trusted the people I was with (V8)." This demonstrates how confidence in their team members' capabilities minimized the stress associated with this deviation from the planned course.

When not as familiar with their colleagues, two HCPs attempted to familiarize themselves with others by looking through the room prior to the resuscitation to learn the name, professional designation, and role in the resuscitation of others in the room. One HCP described the importance of knowing the names of those in the room with them: "I try to remember people's names as much as I can because I find that it helps me to feel more comfortable to talk to people and ask them for things because I can actually say it directly and be more assertive vs. just being like '…[Name of team member] do you mind doing me a favour and getting me a…'(V4)." Another HCP discussed prioritizing those who were involved with the infant's care versus those who were there for another reason: "I did not know who all these people were - whether they were learners or observers I just didn't know. So that is why my eyes went around but the rest of the people I did know and what their roles were. So, I knew who was part of the baby's resuscitation and who was not (V9)."

**3.3.2 Role Assignment and Role Taking**

HCPs discussed how they experienced team dynamics pertaining to their roles in the resuscitation and the roles of those working with them.

When discussing their preparation, HCPs described how roles were assigned before resuscitation. HCPs frequently referred to "standard roles" or roles that the health care team "falls into." One HCP described this tendency as: "A lot of [how roles are assigned here] are professional designation, there are almost standard roles which we tend to take here. RTs [respiratory therapists] often end up being assists or in the background … everyone else was based on the professional designation. So, as a transport nurse, I do often end up taking the airway or head of the bed. We also had another transport nurse who is there on a bedside assignment, and she had to come to help as another airway for the other twin. [Neonatal fellow] was the lead and same thing here that was designated because we typically have either NNP [neonatal nurse practitioner], doctor or fellow whoever comes in as the designated leader, so that is how our system works (V3)."

In one example a HCP who was new to the institution described: "I think that in a centre like this you benefit a lot in that people are very flexible in their roles and you do not have to describe to them exactly what it is that they have to do (V4)." Also, they described why this tendency might have some challenges "But at the same time … when you are coming into a new team that can be very disorienting … I can't get my footing and establish myself as head of the bed if everyone is kind of doing their own thing and it happens without me (V4)." When reflecting on a different resuscitation, one HCP described how explicitly reviewing roles may have been beneficial even when the healthcare team was able to fall into their roles without this discussion; "We probably could have talked about our roles a little more at the beginning but everyone was kind of doing their thing and we're not really listening to each other but I thought it was okay (V7)." A HCP described reviewing roles with the team rather than assigning them prior to resuscitation: "it was nice for me to just reorient myself and my team … to make sure that I had the people that I needed to put the things that I needed to be done even though they will all do it either way and do it incredibly well, but for my own sense of calm it was very nice to have that moment to just check-in and be like ok you are going to record, you are going to do monitors, [assistant] is going to help with the respiratory stuff so these are the people that I can go to (V4)."

In addition to professional designation, HCPs who did assign roles to their team described considering their colleagues' level of experience or comfort. "I like to think about who is going to be most comfortable in that role; there are so many people that could assist at this delivery; there is a new CA [Clinician Assistant] who has never really been to deliveries at our site and I could have given her a role to assist but knowing that she would not feel comfortable in that role and I had more people who would feel more comfortable in that role or be more efficient in that role so I assigned her a different role until she became more experienced (V3)." Several HCPs also highlighted that the individual assigned to a given role must have the capacity to function in that role even if the resuscitation ends up being more difficult or complex than expected. For example, a few HCPs mentioned that the airway lead should be a competent intubator even if intubation is not expected: "So when you are stabilizing an extremely premature baby you would like to have someone who is more senior because when it comes to intubation, that person needs to be able to intubate. So, we consider people who are more senior to get involved in extremely low birth weight babies (V9)."

### 3.3.3 Navigating Leadership

HCPs also discussed their obligations as a leader in the resuscitation and how the team composition affected these obligations. One HCP described their perspective as a leader in the resuscitation: "[There is a] balance of being a leader in a scenario and accepting that you have exceptionally talented colleagues that know what they are doing and have an excellent grasp of their roles and your roles. Knowing that these roles can be organic and kind of meld into one another so that it does not all fall to me. But at the same time, I am also responsible to be that team member to my other team members (V4)." Another HCP who acted as the airway lead during a resuscitation discussed how she managed this role and how despite there being an additional team lead she was still in charge of leading and managing a smaller sub-team: "so the team lead … makes sure that everyone is on the same page and she coordinates the process, but with the respiratory, I was coordinating with my respiratory therapist with regards to the respiratory part of the baby asking about air entry and pressures (V9)." A different HCP who was acting as an airway lead in the recorded resuscitation described being aware of how her role in this complex delivery differed from resuscitation where an additional leader is not present: “I was managing the airway so I was doing all of the respiratory breathing for the baby so I was head of the bed but someone else was leading what we were doing and the process of resuscitating the baby so this doctor was off to the side… I do not have as much authority during these complex deliveries because I am there to do the procedures at the head of the bed more hands-on (V5).” She added that this dynamic “is a relief because it is a lot of responsibility when you have a complex resuscitation; you need more hands - you cannot just do it with two people because it would compromise the baby's care (V5).”

### 3.3.4 Using Guidelines to Support a Shared Understanding

HCPs referenced policy and guidelines to comprehend the action of their team members and therefore develop shared understandings. For example, HCPs knew that delayed cord clamping would occur after birth without discussing this with team members and HCPs recognized that a research assistant was adjusting the fraction of inspired oxygen settings per a clinical study protocol again without discussion of this. HCPs described how a shared knowledge of protocols not only helped them to develop a shared understanding of the current situation but also helped them have a similar idea of how the intervention would progress. “We always assess, intervene, assess and when it wasn't working, we moved on as far as MR. SOPA (V6).” This HCP was referring to the set of corrective steps outlined in the NRP to improve mask ventilation.

### 3.3.5 Information Sharing

HCPs described how they shared information within and between team members to develop a common understanding of the resuscitation. Information about the infant’s status and medical history was shared most frequently during the resuscitation, as observed from eye-tracked video and HCP’s recall. Information sharing was described both when the information was available to all team members (e.g., sharing the infant's heart rate when it was displayed on the monitor or infant’s colour to an assistant who was also looking at the infant) and when the information was limited to or more accessible to one individual or team than the receiving party (e.g., when an assistant shared heart rate before it was available on the monitor or shared perceived air entry after auscultating). Information sharing also took place between the obstetric and neonatal teams during delivery and delayed cord clamping. For example, one HCP described vocalizing the time on the Apgar timer: "I'm communicating the time through the doors, so they know how long you've been doing delayed cord clamping (V6)." When waiting in the resuscitation room unable to see the infant in the operating room, an HCP noted: "At this point, the person at the door had told us that the baby is vigorous and crying (V3)." In another instance, an HCP described the value of not hearing information from the other team: "so it is a no news is good news situation, if they were concerned they would have said something so we are trusting our team in that scenario and the obstetrician (V1)." In this case, the lack of information being transferred itself acts as a source of information sharing.

Some HCPs also described a potentially problematic lack of information sharing between and within teams. In one case a HCP described learning the maternal history from a colleague in the NICU team directly before the arrival of the infant because of a "communication failure" between labour and delivery and the NICU team earlier in the process: "I did not get a full report, but the mom was positive for syphilis just two weeks prior too (V3)." This history changed her anticipation: "So that information changes things because we were going from babies that we were not expecting to be unwell because there were no risk factors for sepsis to now finding out this information and thinking 'oh wow these babies may come out very unwell if they have been exposed to syphilis infection.'" She then described how this information would change how she went about the resuscitation: "we will need blood work off the placenta, so it became more of that. OK, who can we reassign a role to be able to get that blood work. So, at that moment, I was thinking okay who is going to draw up the placenta; we will have to do blood work."

In addition to sharing information about the infant's current status, HCPs described sharing their clinical decision making with colleagues. This behaviour was described by one HCP as an effort to keep everyone “in the loop.” A HCP described sharing their thoughts: “I was trying to talk out loud so that everyone knew what I was thinking about (V3)” or “I just have a running dialogue so that everyone can hear what I'm thinking (V10).” One HCP described the information that they included in their think-aloud to their team as “more so what it is that I'm seeing and then what my decision and thought process is. So, for example, here I was saying ‘oh I am about to start PPV but then every time I go to start the baby starts breathing,’ just so that my assistors know that I am recognizing that the baby may need PPV but there is a reason why I have chosen not to start” adding that “I really appreciate it when other people [talk aloud] for me, so I tried to do it for other people as well (V3).” Some HCPs described their lack of sharing their decision making as a limitation to their performance when reflecting on the recordings. For example, one HCP felt frustrated with the lack of urgency her team was displaying as they prepared for the imminent arrival of the baby: “Why was no one else trying to help me gather more people or questioning me about whose team they are supposed to be on? These babies are delivering right now, mind you I did not say that; I could have vocalized ‘these babies are coming right now!’ (V8).”

### 3.3.6 Mutual Support

In addition to providing information about the infant’s status and their thinking during the procedure, HCPs described various other team behaviours that supported the resuscitation, including providing feedback and criticism and management of workload within teams.

*Providing feedback and criticism*

HCPs described various ways of supporting each other during resuscitation. Team members noticed errors or opportunities for improvement in performance. Some HCPs shared these observations and critiques with their team. For example, a HCP described teaching a colleague to properly use a probe when they realized it was not picking up a consistent recording: “The RT [respiratory therapist] was new so we have the probe on but sometimes we need to hold it little bit or this posey helps to get a better reading so I was explaining that (V10).” In another example, a HCP described noticing a colleague unnecessarily disturbing the infant and responding accordingly: “This person who was assisting with the resuscitation, I'm not sure what her background in neonatal resuscitation was, but her shaking the baby's leg like that really irritated … so I needed to politely ask her to not do that because the baby was fine. We just needed to make the baby a nest and let the baby settle while CPAP was going on (V2).” One HCP stated: “the way that people provide feedback- it's an important indication of how the team is working together (V1),” highlighting the importance of this behaviour.

At times, HCPs described recognizing an error or flawed performance by a team member during the resuscitation but not sharing this concern/realization. For example, one HCP described: “I would have probably liked [Assistant] to have stimulated a little bit more while I was putting the hat on (V1)” but did not mention anything to the assistant. When asked why they were hesitant to speak up or vocalize critiques, HCPs described being focused on their own performance “I am focusing on my steps and what I am doing (V1).” HCPs also tried not to overburden their colleagues: “It is also really annoying when you were in a situation and you do not have enough personnel and people are asking you to do tasks that do not need to be done at that time (V8).” Some HCPs cited the experience level of their colleagues when considering whether to speak up or not; “[Assistant] has been doing this for a very long time… if it had become an issue, then I would have said something (V1).” This same HCP noticed when reflecting on her interactions in the recording that “The longer I do the job the better I get at asserting myself (V1),” suggesting that it is not only the experience level of her colleague but also her experience level that contributes to her decision to speak up.

*Receiving Feedback*

In addition to providing feedback, HCPs also discussed receiving feedback and criticism from colleagues and integrating this into their performance. One HCP described giving her team members permission or encouraging them beforehand to give her feedback: “I remember consciously thinking ‘ok I am going to need help with this and I do not want people thinking that they cannot tell me because they do not know me,’ so chatting with [colleague]…I wanted to make sure that she knew that I knew what my experience was so that she would feel more willing and able to jump in and provide technique [suggestions] (V4).” Later in the recording, she described how a colleague’s encouragement/ feedback helped her decide on the appropriate actions: “there was a moment in my head… is it too soon for me to do this? Should we try something else first? In terms of getting started with PPV when the heart rate goes below 100 … I had [supervising colleague] right there who said the heart rate is now below 100, and I said ‘OK, so start PPV?’ and he said yes, and I said ‘ok perfect’ so to have that piece there [was good] (V4).”

In contrast, some HCPs did not feel that the feedback they received was beneficial. One HCP felt that the feedback provided to her was detrimental to her focus. “I found that I was doing all my steps and I know she was just trying to help - asking me if I had done these things and it was distracting at that point but I had already done them so it ended up being fine (V1).” Later in their discussion, this HCP noted: “There are definitely some personalities which are trickier and you do not feel as confident with so I think them critiquing you and the way that they are critiquing you can affect your confidence level (V1).”

*Workload management*

HCPs discussed monitoring individual and team workload during the resuscitations. HCPs noted monitoring for delays in task completion or decreased quality of performance as an indication of excess workload level. For example, one HCP described monitoring their team: “Looking at the situation and seeing what is going on to see if team members and myself can complete tasks that we are assigning. If you are assigning tasks and they are not being completed before you are assigning another task, then maybe their workload is too much (V3).” Another HCP described how she monitored team workload using similar indicators to the previous example: “when I see either dysfunction in the communication that is happening or I am starting to see that the quality of what is being done is not the same as it used to… it is the outcome that ends up bringing it to your attention too, like the baby's heart rate. Then what is the problem? Have we spent too much time suctioning? Are we not adequately ventilating? Have we missed something? So then at that point, I look through and will sort of try to troubleshoot. Which is a bit more reactive than proactive but is usually what I end up doing (V4)."

HCPs described the various ways they adapted after recognizing that the workload of an individual or team was very high. When possible, HCPs described calling for additional help: "I wanted to make sure that she was not feeling stressed about managing too many things at once so I got [Assistant] to go and see if we had any extra staff to come down and give us a hand getting our kid on CPAP (V1)." Alternatively, they described delaying unnecessary task assignments and encouraging their colleagues: "If you do not have extra help trying to prioritize what needs to be done at this moment versus what can wait" or trying "to either relieve the load or give some positive feedback so that [the colleague whose workload is high] does not feel as stressed (V7)." This prioritization was demonstrated in an example where placental sampling was required. The HCP described the situation: "Before she needed the PPV I [thought] 'I'll get someone to go [do placental sampling],' but then I [thought] 'oh no I'll actually need her help because I do not know if we will need to do more for the baby.' I wanted to keep her at the bedside. And then seeing how busy they were with the other baby too [the infant's twin], I was thinking this was not a good time for her to go and do blood sampling. I was just trying to prioritize what needed to be done and that was low on the totem pole (V3)." When one HCP felt that the physical demand she was experiencing was too much, she described swapping out with a colleague: "We are switching out because my hands completely cramped up, so I just went to assisting now (V5)." HCPs described deliberately prioritizing tasks to optimize the team members who were available when human resources were limited.

## 3.4 Addressing Threats to Performance

HCPs discussed barriers to situation awareness, performance, and teamwork during resuscitation, including limited resources, equipment issues, mental stress, distraction, and parental presence.

### 3.4.1 Limited Resources

As discussed in the workload management subtheme, some HCPs reported needing to cope with limited human resources such as inadequate team size or missing a team member, resulting in delays and difficulties.

### 3.4.2 Equipment Issues

HCPs frequently described equipment issues as a barrier to performance during resuscitation. Most commented-on delays or errors with monitoring equipment, lack of space within the resuscitation room, and ergonomic challenges associated with an additional sensor on the T-piece required for respiratory function monitor. Delays in the availability of accurate readings from monitoring equipment occurred for a variety of reasons (e.g., technical glitches, people using them incorrectly, and problematic monitor settings). When delays occurred, this slowed the resuscitations as HCPs reported waiting to obtain an accurate recording or taking time to consider what information to rely on when the monitor seemed to be inaccurate. For example, this HCP described noticing a discrepancy between the patient's appearance and the values displayed on the monitor: “She looks pinker than what the number [oxygen saturation] is saying so you know sometimes it’s just due to equipment failure versus the actual baby and how they are doing medically (V2).” They described how this affected their care: “So now I'm waiting to get a good reading so we can give her less oxygen and then we will start the CPAP with the other machine (V2)” and the potential consequences this had on the patient: “This did affect the way the resuscitation went because the baby ended up needing more oxygen based on a false number, potentially (V2).”

Limited space within the resuscitation rooms was discussed as a barrier to performance as it "is always really tight so if you are moving around a lot… or had wanted to intubate or anything, then it can be frustrating to bring (equipment) (V1)." Many HCPs also discussed challenges using the T-piece due to the addition of a sensor for a respiratory function monitor. HCPs felt that this piece was cumbersome to work with and may have caused them to place extra pressure on the infant's face when providing CPAP or PPV. HCPs noted: "I may have even done some Vagal on the baby's face by compressing the mask on to the baby's face because I was also trying to balance and keep it upright. The capnometer was a little heavy for my hands (V9)." Similarly, another HCP noted: "the [extra sensor] is more cumbersome to work with; it does not have the same feel as without it (V7)."

### 3.4.3 Mental Stress

Some HCPs reported feeling overwhelmed or frustrated during resuscitations. At times this stress was linked to situational factors. These included feeling scrutinized (e.g., "I did feel super self-conscious because of the glasses and there was a lot of people watching (V6)"), unfamiliarity with the setting (e.g., "No beside the added cognitive load of a being in a spot that is new and trying to re-orientate myself to like I know all of these equipment pieces should be in here but in an environment where you are familiar with it (V4)"), or lack of experience (e.g., "in the event of intubation I'm certified but I'm not an experienced intubator; I have only intubated … five or six times so having a larger gestation I was confident that I could get the tube but it was an extra thing that I had to think about in the back of my mind" (V6)). There were also personal circumstances that were described relating to stress. For example, "I was very hungry, I'm super busy, and this is going to sound selfish when you have not had a break all day and you are starving there's that moment … this is going to take me at least an hour before I can go upstairs and have something to eat. So, I very much felt that (V8)." One HCP described how they mitigate tensions and stress using "black humour" describing how they were "not making light of the situation by any means, but we are taking some of the stress out of a potentially stressful situation. And then it is also like team camaraderie; everyone is in it and it builds relationships to get some common ground (V3)."

### 3.4.4 Distraction

The presence of distractors or irrelevant stimuli during HCPs' preparations for and participation in resuscitations was evident in video recordings. Potential distractors included irrelevant conversations between colleagues, phone calls from the NICU or labour and delivery, the resuscitation of other infants in the same room, and unnecessary alarms. HCPs did not frequently discuss the presence of these distractions until prompted by the interviewer. When asked, most HCPs were aware of the distractions but felt that they effectively dismissed them in the recorded resuscitation, describing that the distraction did not significantly influence their performance. For example, when asked if a ringing phone in the recording had affected the resuscitation or their thought processes, this HCP responded: "No - I just had someone else get the phone or if it is not my phone, they can handle their own phone because I have to keep giving PPV. There we go someone is grabbing my phone (V5)." Furthermore, another HCP who discussed being distracted by a team member during preparation for a resuscitation also demonstrated her ability to dismiss a distractor and focus on what was necessary for the resuscitation: "So you can see that it interrupted what I was trying to say at that point. I do not even remember what was asked of me in the background. I cannot even make it out in the video, but you can see me taking my attention away, and then coming back. Fortunately, here it looks like I was able to finish my train of thought so that was good(V3)." This same HCP later reflected "My attention was pulled - I remember my phone ringing a lot during this resuscitation which was not really captured in the video and then some people coming in and wanting my attention when I was busy doing other things, but I feel like I manage and was able to pull my attention back to what needed to be done (V3)."

### 3.4.5 Parental Presence

HCPs discussed how they felt about the presence of parents (all of whom were a father in the recorded videos) in the resuscitation and stabilization room and how a parent's presence did or did not affect their performance.

HCPs expressed several concerns associated with the presence of family members in resuscitation, including worrying about how parents will cope, the extra demand that this may place on the healthcare team, and compromising the sterility of the room/procedure. These concerns prompted some HCPs to ask that the father wait to enter the resuscitation room. This was the case when one HCP told the labour and delivery staff not to have the father enter the room when they asked, later stating that "at that time we were needling him and not being able to ventilate him and then after this he ended up coding so we did not invite dad in at this time until all of these complex things were done…. sterile procedures were going on, and it may be traumatic for the parent, and I do not know if there was anyone available to lead and diffuse the parent at that time, so it was a choice to have dad remain outside at that point until it was ok for him to come in (V5)." Again, the following example displays HCP reluctancy to invite the father into the resuscitation initially: "I feel that having parents there definitely impacts the resuscitation and I prefer to wait until the baby is a little more stable before they come in. I do not feel it has to do with how I am doing- more so the stress that I am causing them. I know that studies have shown that parents want to see this, but I just think that it would be so scary so I would prefer if their child is a little bit more stable before they come in (V7)."

In addition to concerns for the parents, HCPs also were worried about how parents' presence would affect the team performance during the resuscitation. For example, one HCP described why they would typically like the parent(s) to wait to meet their infant if they are quite compromised at birth until after the initial resuscitation "I am in this state where we need everyone to concentrate and if a parent is walking in … and we are trying to get an intubation we need to focus on getting that work done. If parents come in and are hysterical or asking a lot of questions... that is just not the time for that (V10).” They added that “the baby does not need to be perfect for me to allow the parents in, but if something needs to happen first, I would like to get that done and then have the parents come in (V10).”

In contrast, some HCPs felt that the father’s presence had no or little effect on their performance. HCPs discussed being too focused on their role in the resuscitation to be negatively affected by the father’s presence. For example, “The dad did not (affect me) because I still need to focus on the primary task at hand, and I need to talk to parents at the same time so... it is fine (V2).” Similarly, “I know that me being concerned about airway and initial resuscitation, I often do not think about parents until we know the baby does not need any more at that moment (V3).”

In some cases, HCPs noted that they had no say in the decision to have the father in the room, as labour and delivery HCPs brought the father into the room without asking, or they felt it necessary to obey with hospital policy. “I do not remember verbalizing. I think that labour and delivery just opened the door and sent him in(V2).” When asked how they felt about this, the HCP responded, “well, we have to be [ok with the father's presence] because we are family-centred care so we have to explain to him what is going on (V2).”

Furthermore, some HCPs felt that it might be better to have the parents in the room. In one example, a HCP suggested that being present during resuscitation may benefit some parents and negatively impact others, stating: “I think it ultimately depends on the parent's comfort level (V1).” Another HCP felt this way as well, stating: “I know if I were a parent, I would want to be there, so I do not know why we do not bring them in sooner... Sometimes because the mom has just had surgery, I have asked, and they have opted to stay with the mom to make sure that she will be okay. But I think that us getting the parents in the sooner could definitely be done (V3).”

### 3.5 Perception of Eye-tracking

All participants felt that reviewing their eye-tracking recordings helped them to recall their thought processes during the resuscitation. One HCP said, “I was able to remember exactly what I had to think about and consider with him (V10).” Another HCP felt that this method of review was especially helpful given the busy nature of resuscitation: “because your memory is not as good when you're in a situation with a little bit more happening (V6).”

While watching the recordings, some HCPs noted that they were behaving in a manner they were not conscious of during the resuscitation. One HCP, for example, noted “to soothe my own nerves, constant re-checks are what I will often use to kind of remind myself that things are ok. [This is] definitely is something that I do more than I thought that I did (V4),” after noticing the number of times they had looked through the equipment and clarified important points with colleagues in the recording. Some HCPs were surprised by their visual attention during the recording. Many participants noted the speed with which their focus changed. “I thought the video was going in fast forward (it was not), but I think I just don't realize how much I'm really looking around at things. it's interesting to watch that after (V10)” and “Wow, my eyes really go all over the place; I did not realize I was looking around that much (V2).” One HCP noted that they felt “more cognizant” of what they should be doing during the resuscitation because of their awareness of the eye-tracking glasses recording their actions. This participant did later state, “but now I am thinking I would still do the same things as I did in the video (V7).” Another HCP noted feeling “super self-conscious because of the glasses and [because] there were a lot of people watching (V6).”

The recording also prompted HCPs to recall their emotional experiences during the resuscitation. For example, when hearing their tone of voice in the audio recordings, HCPs noted: “I was excited you can hear my voice increase (V10)” when describing how the infant had started to cry on their own. Or “you can hear it in my voice as well- I do not typically talk that fast (V8)” when describing their rushed preparation for the arrival of the infant. Further, a participant watched as their gaze moved to the oxygen saturation reading on the infant's monitor shortly after delivery and recalled feeling surprised: “But it is so funny to watch that and be like ‘Oh Wow!’ 85-something is weird (V8).” This surprise prompted realizing that the fraction of inspired oxygen was set at 100% higher than policy mandates.

Generally, HCPs seemed to enjoy reviewing their recordings, and several HCPs asked if they could participate again, citing this review as a learning opportunity for themselves.

### 3.6 Limitations

This project had several limitations. Our sample did not include any neonatal nurse practitioners or neonatologists. These HCPs often perform neonatal resuscitations and may have a different approach to this task. Participants were generally experienced in neonatal resuscitation and I did not compare the think-alouds of novices and experts. None of the recorded resuscitations included intubation or chest compression, so HCPs’ cognitive processes during these complex procedures were not examined. Further, all recordings took place in a single institution, so the themes that were derived may have been influenced by HCPs’ shared experiences, education, and the culture of the institution in which recorded resuscitations took place.

The Hawthorne effect may have affected our results as HCPs were aware that they were being observed and recorded during their participation in resuscitation. Therefore, they may have modified some aspects of their behaviour. This may have been the case for all members of the healthcare team, not just the individual wearing the eye-tracking glasses. The gaze patterns of participants may have also been altered as they were aware that their gaze patterns were being monitored by the eye-tracking glasses[154].

HCPs were allowed to describe, explain, and generalize their thoughts during the think-aloud process. These explanations are level 3 verbalizations (as described in Chapter 2), which may be less valid than level 1 and level 2 verbalizations[114,155]. Further, by probing participants and asking questions during the video review, I may have contributed to this effect. Directed probes and questions that force participants to make inferences about their thinking lead to level 3 verbalization[114,155]. In future projects using these methods, interviewer questions should be delayed until the think-aloud is complete.

Finally, as the think-alouds were completed retrospectively, participants may have an incomplete or manipulated recall of their cognitive processes, which occurred during the recorded resuscitation[119,120].

**Figure 3.1** Summary of Themes and Subthemes

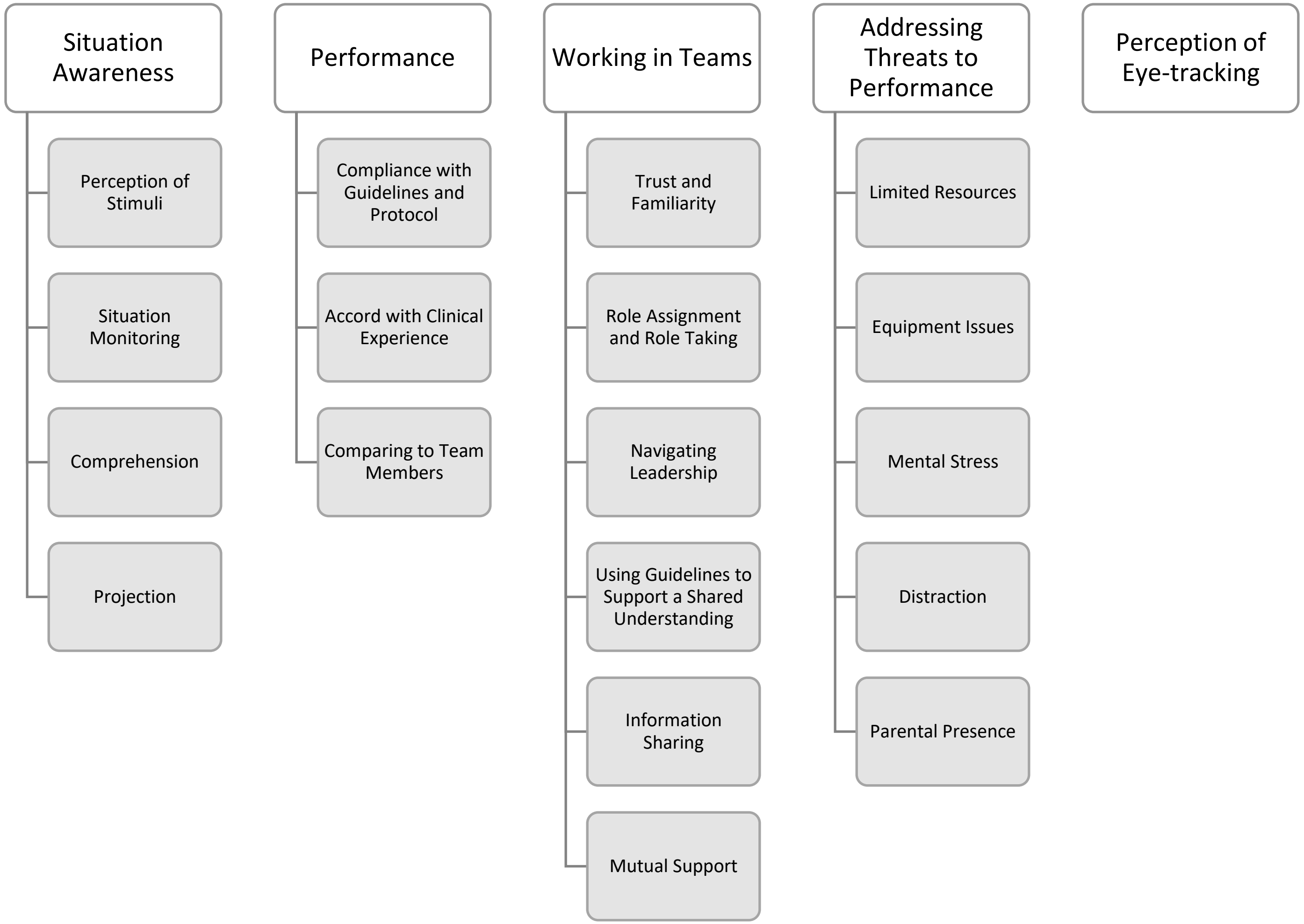


**Table 3.1** Characteristics of recorded neonatal resuscitations and participant's demographics

| Case ID | Participant ID | Professional Designation | Role in Resuscitation | Experience with Neonatal Resuscitation (years) | Estimated Frequency of Participation in Neonatal Resuscitation | Infant's Gestational age (Weeks+ days) | Infant's Weight (g) | Interventions Required in Initial Resuscitation | Time from birth to infants heart rate to increase over 100 | Infants Condition |
|---|---|---|---|---|---|---|---|---|---|---|
| **V1** | 1 | RN/ TN | Transport Nurse / Airway Lead | 7 | >1/week | $30^{+0}$ | 1,230 | CPAP, PPV | 4 min | Twin growth discrepancy |
| **V2** | 2 | RN / TN | Transport Nurse / Airway Lead | 10 | 6-30/week | $33^{+6}$ | 2,430 | CPAP, PPV | 10 min | Vasa previa-anterior |
| **V3** | 3 | RN/ TN | Transport Nurse / Airway Lead | 10 | 5-20/week | $31^{+2}$ | 1,450 | CPAP, PPV | Always >100/min | Premature infant |
| **V4** | 4 | Neonatal Fellow | Team Lead/ Airway Lead | 3 | 1-2/week | $26^{+5}$ | 940 | CPAP, PPV | Always >100/min | Premature, monochorionic, diamniotic twins |
| **V5** | 2 | RN/ TN | Airway Lead | 10 | 15-20/week | $35^{+0}$ | 3,000 | CPAP, PPV, Needle Thoracentesis | 4 min 30 sec | Hydrops fetalis |
| **V6** | 5 | RT | Airway Lead | 2.5 | 1/ week | $35^{+6}$ | 2,630 | CPAP, PPV | Always >100/min | Not specified respiratory distress |
| **V7** | 6 | RN/ TN | Team Lead/ Airway Lead | 15 | 12-16/week | $28^{+2}$ | 1,310 | CPAP, PPV | 10 sec | Premature infant |
| **V8** | 3 | RN/ TN | Transport Nurse / Airway Lead | 10 | 5-20/week | $29^{+0}$ | 1,405 | CPAP | Always >100/min | Premature |
| **V9** | 7 | Neonatal Fellow | Team Lead/ Airway Lead | 10 | 3-8/week | $28^{+0}$ | 860 | CPAP, PPV | 5 min 10 sec | Premature Maternal HELLP Syndrome |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **V10** | 8 | RN | Team Lead/ Airway Lead | 12 | 12-16/week | $39^{+0}$ | 3,610 | No respiratory support | 30 sec | Coarctation of the Aorta |

**V-video, RN-registered nurse, TN- transport nurse, RT-respiratory therapist, CPAP- continuous positive airway pressure, PPV- positive pressure ventilation**

# Chapter 4. Healthcare Professionals Subjective Workload in Neonatal Resuscitation

This chapter consists of slightly modified sections from an article, which is currently under peer-review in Archives of Disease in Childhood - Fetal and Neonatal Edition. “Does parental presence affect workload during neonatal resuscitation?” and from the article “Assessment of healthcare provider workload in neonatal resuscitation,” which is currently under peer review in PLOS One.

## Overview

Excess workload in health care settings can negatively impact patient safety[68,69 7071]. Given the dynamic, fast-paced, and high-stakes nature of neonatal resuscitation, workload may play an important role in how HCPs perform individually and as a team. Understanding the workload experienced by HCPs during neonatal resuscitation might reveal opportunities to improve performance, decrease errors, and therefore improve patient safety. This project aims to investigate HCPs' perceived workload and to determine the relationship between roles, the complexity of care, and parental presence during neonatal resuscitation in the delivery room using a modified NASA TLX survey.

# Results

## 4.1 Demographics

In total, 204 surveys were completed: 105 (52%) by registered nurses. 40 (20%) by transport nurses, 14 (7%) by neonatal nurse practitioners, 22 (10%) by respiratory therapists, 4 (2%) by residents (R1-4), 9 (4%) by neonatal fellows, 6 (3%) by neonatologists, and 4 (2%) by students. HCPs had a median (IQR) of 14 (7-18) years of experience working in the NICU. 168/204 surveys were from female HCPs, 23 from male HCPs, 2 from HCPs who identified themselves as being neither female nor male and 11 from HCPs who did not identify their gender. Overall, HCPs' roles during resuscitation were team leader 33 (16%), airway manager 52 (26%), team leader + airway manager 16 (8%), nurse 67 (33%), respiratory therapist 15 (7%), recorder 6 (3%), observer 4 (2%), and students 11 (5%). Demographics of infants whose deliveries HCPs attended, time to prepare for delivery, and interventions performed during resuscitations are presented in Table 4.1. In 135 (66%) deliveries parents were present, in 48 (24%) they were not, and in the remaining 21 surveys, HCPs did not provide an answer.

**Table 4.1** Demographics of included infants, time to prepare to attend the delivery, and interventions performed during resuscitations

| **Demographics of included infants** | |
|---|---|
| Gestational Age (weeks)† | 35 (5) |
| Birth Weight (grams)# | 2690 (1830-3440) |
| Apgar-Score 1 minute | 6 (4-8) |
| Apgar-Score 5 minute | 8 (7-9) |
| Female infants | 85 (43%) |
| Caesarean Section | 135 (67%) |

| **Time to prepare to attend the delivery** | **N=202** |
|---|---|
| Emergency Code | 9 (5%) |
| Arrived after delivery | 20 (10%) |
| 0-5min | 61 (30%) |
| 5-10 min | 48 (24%) |
| 10-20 min | 28 (14%) |
| 20+ min | 36 (18%) |

| **Interventions performed during resuscitation** | |
|---|---|
| Stimulate | 149 (73%) |
| Suction | 130 (64%) |
| Continuous positive airway pressure | 120 (59%) |
| Positive pressure ventilation | 105 (52%) |
| Intubation | 33 (16%) |
| Chest Compression | 10 (5%) |
| Epinephrine | 4 (2%) |

Data are presented as n (%), unless indicated #median (IQR), †mean (SD)

## 4.2 Dimension Score

The median (IQR) dimension score (out of 20) of mental demand was 10 (5-14), for physical demand 4 (1-6), for temporal demand 8 (3-14), for performance 4 (2-6), for effort 8 (4-13), and frustration 4 (1-10) (Figure 4.1). The dimension scores, the sum of the dimension score, and Raw-TLX divided by HCP's role during resuscitation are presented in Table 4.2.

**Figure 4.1 NASA TLX Score by Dimension.** NASA TLX Scores by dimension (y-axis). Box plots represent median values (solid bar), IQR (margins of the box) and whiskers as a 95% confidence interval.

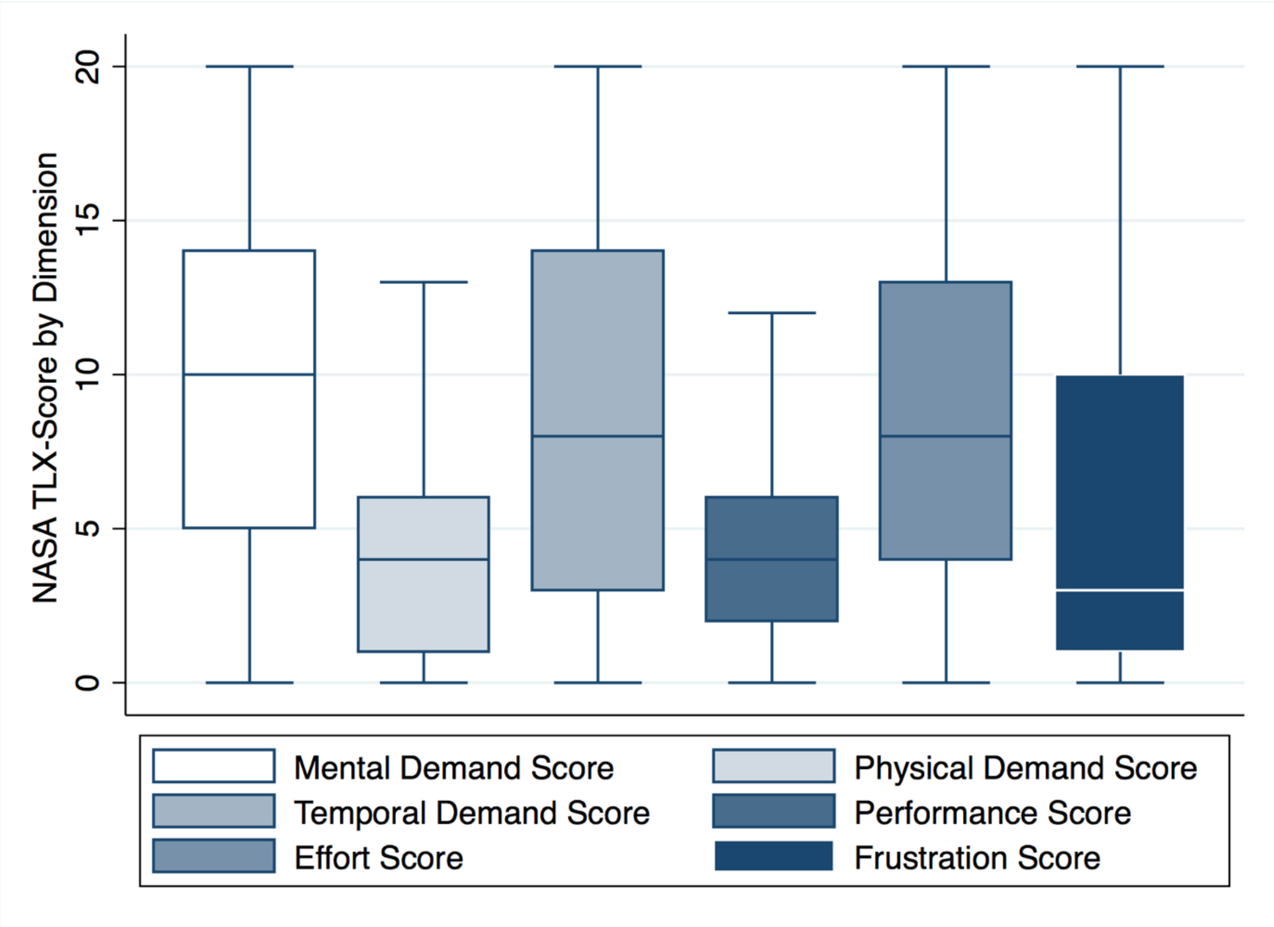


**Table 4.2** Dimension score by role, the sum of dimension score and Raw-TLX score

| | Mental Demand Score | Physical Demand Score | Temporal Demand Score | Performance | Effort | Frustration | Sum of Dimension Scores | Raw-TLX Score |
|---|---|---|---|---|---|---|---|---|
| Team Leader (n=49) | 8 (4-15) | 3 (1-5) | 5 (2-14) | 3 (2-5) | 7 (3-12) | 2 (1-9) | 32 (15-55) | 27 (13-46) |
| Airway Manager (n=66) | 10 (6-15) | 4 (2-6) | 7 (3-13) | 4 (2-5) | 9 (4-14) | 3 (1-8) | 40 (25-56) | 33 (21-47) |
| TL+AM (n=16) | 10 (6-15) | 3 (2-6) | 7 (2-14) | 4 (3-5) | 10 (4-13) | 3 (1-10) | 38 (21-55) | 31 (17-46) |
| Registered Nurse (n=69) | 10 (3-14) | 4 (1-7) | 8 (3-14) | 4 (2-6) | 8 (4-14) | 3 (1-11) | 41 (22-58) | 34 (18-48) |
| Respiratory Therapist (n=15) | 12 (8-14) | 4 (3-5) | 15 (11-18) | 5 (4-12) | 9 (7-14) | 8 (4-14) | 59 (46-74) | 49 (38-62) |
| Recorder (n=6) | 13 (9-16) | 4 (5-6) | 13 (8-14) | 5 (4-7) | 7 (5-11) | 8 (1-12) | 52 (42-59) | 43 (35-49) |
| Observer (n=4) | 5 (2-16) | 2 (1-3) | 9 (5-14) | 3 (2-4) | 4 (3-5) | 3 (2-3) | 20 (15-36) | 16 (12-30) |
| Student (n=12) | 10 (5-13) | 5 (2-7) | 10 (4-11) | 4 (3-6) | 10 (6-14) | 6 (2-10) | 42 (30-56) | 35 (25-46) |

Data are presented as median (IQR); TL+AM, team leader + airway manager

## 4.3 Raw-TLX Score

The overall median (IQR) Raw-TLX (overall workload score) was 34 (18-49). The Raw-TLX was higher when HCPs performed any interventions compared to no interventions with 35 (22-49) vs. 8 (6-18), p=0.0011; (Figure 4.2A). Furthermore, the Raw-TLX was higher during positive pressure ventilation vs. no positive pressure ventilation with 46 (33-57) vs. 25 (11-38), p=0.0001; (Figure 4.2B). Similar with intubation vs. no intubation 55 (46-62) vs. 30 (17-46), p=0.001; (Figure 4.2C), and chest compression vs. no chest compression 55 (49-64) vs. 33 (18-47), p=0.001; (Figure 4.2D).

The Raw-TLX in the low 5-minute Apgar score group was 54 (48-61), compared to the medium or high 5-minute Apgar score groups with 47 (36-58) and 28 (14-28), respectively. One-way ANOVA revealed significantly higher Raw-TLX in the low and medium 5-minute Apgar score groups compared to the high 5-minute Apgar score groups (p=0.001).

Overall, the Raw-TLX was similar, regardless of HCP roles during resuscitation (Figure 4.3).

**Table 4.3** Description of workload dimensions considered in NASA TLX adapted from NASA TLX Paper and Pencil Version Instruction Manual[156]

| Title of Dimension | Endpoints | Description Provided | Example of Contributor |
|---|---|---|---|
| **Mental Demand** | Low- High | How much mental and perceptual activity was required | “Active resuscitation- looking/ assessing many different things and listening to instructions from the team lead.”<br><br>“First delivery where I recorded, so lack of knowledge was the main contributor.” |
| **Physical Demand** | Low- High | How physically demanding was the task? Was the task easy or demanding, slow or brisk slack or strenuous, restful or laborious? | “Room too small, no place to put supplies.”<br><br>“Running to set Viasys up in a timely fashion.” |
| **Temporal Demand** | Low- High | How much time pressure did you feel due to the rate or pace at which the task or task element occurred? Was the pace slow and leisurely or rapid and frantic? | “Heart rate was low and not responding.”<br><br>“Calm organized team, senior.” |
| **Performance** | Good-Poor | How successful do you think you were in accomplishing the goal of the task? How satisfied were you with your performance in accomplishing these goals? | “Good NRP (Neonatal resuscitation protocol) and teamwork.”<br><br>“Experience allowing me to anticipate what would need to be done.” |
| **Effort** | Low-High | How hard did you have to work (mentally and physically) to accomplish your level of performance? | “It was late. I was tired.”<br><br>“New to transport role still building confidence in a role, especially when performing resuscitation without 2nd NICU team member.” |
| **Frustration** | Low- High | How insecure, discouraged irritated, stressed and annoyed vs secure, and complacent did you feel during the task | “Team made it easy despite difficult issues.”<br><br>“More frustrated with lack of communication from labour and delivery and unpreparedness.” |

**Figure 4.2 Raw-TLX scores based on intervention performed.** Raw-TLX scores (y-axis) of healthcare providers attending deliveries in which the baby either required A) any delivery room(DR) intervention vs. no delivery room intervention, B) positive pressure ventilation (n=105) vs. no positive pressure ventilation (n=99), C) intubation (n=33) vs. no intubation (n=171), and D) chest compression (n=10) vs. no chest compression (n=194). Box plots represent median values (solid bar), IQR (margins of the box) and whiskers as a 95% confidence interval.

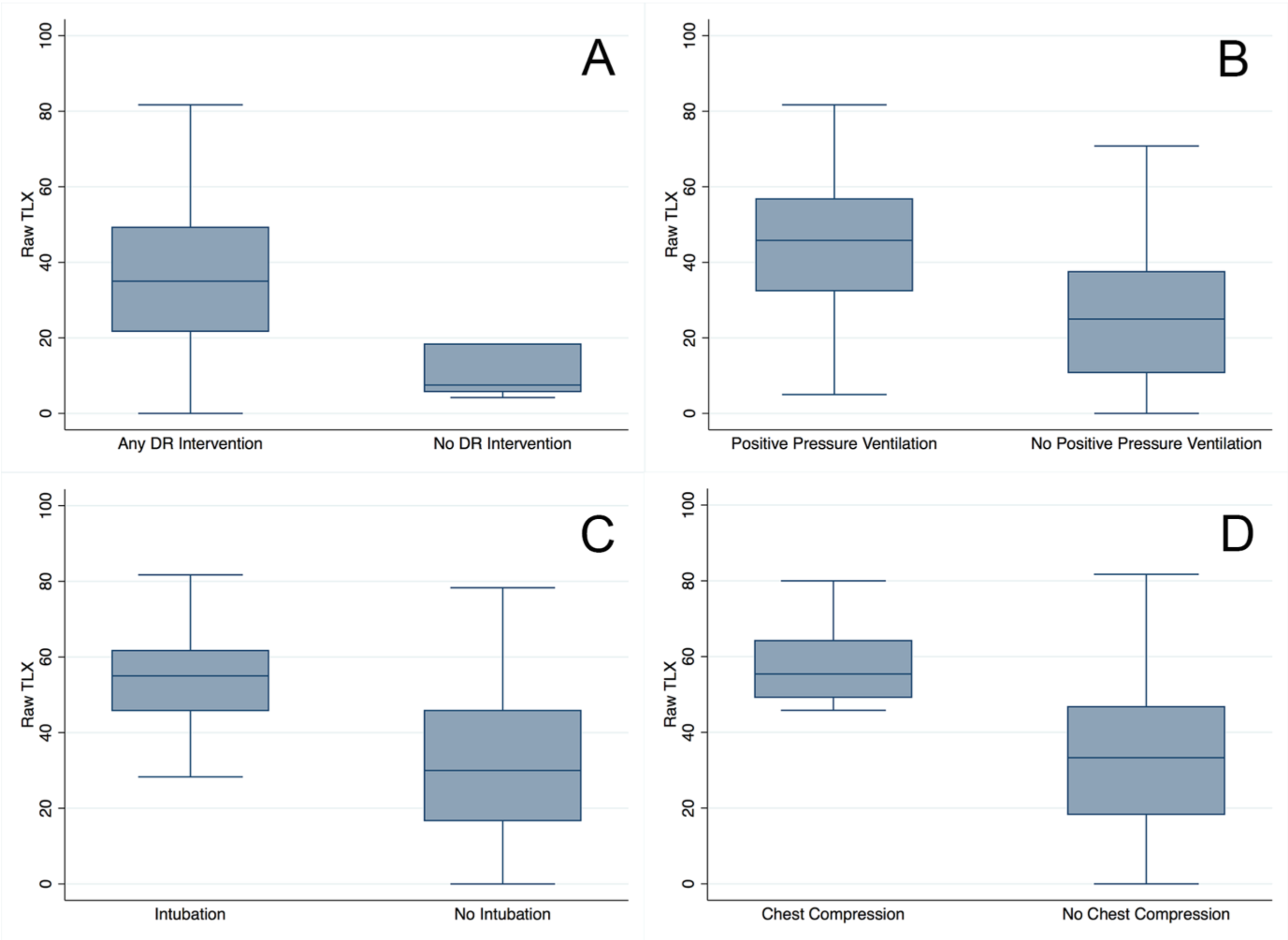
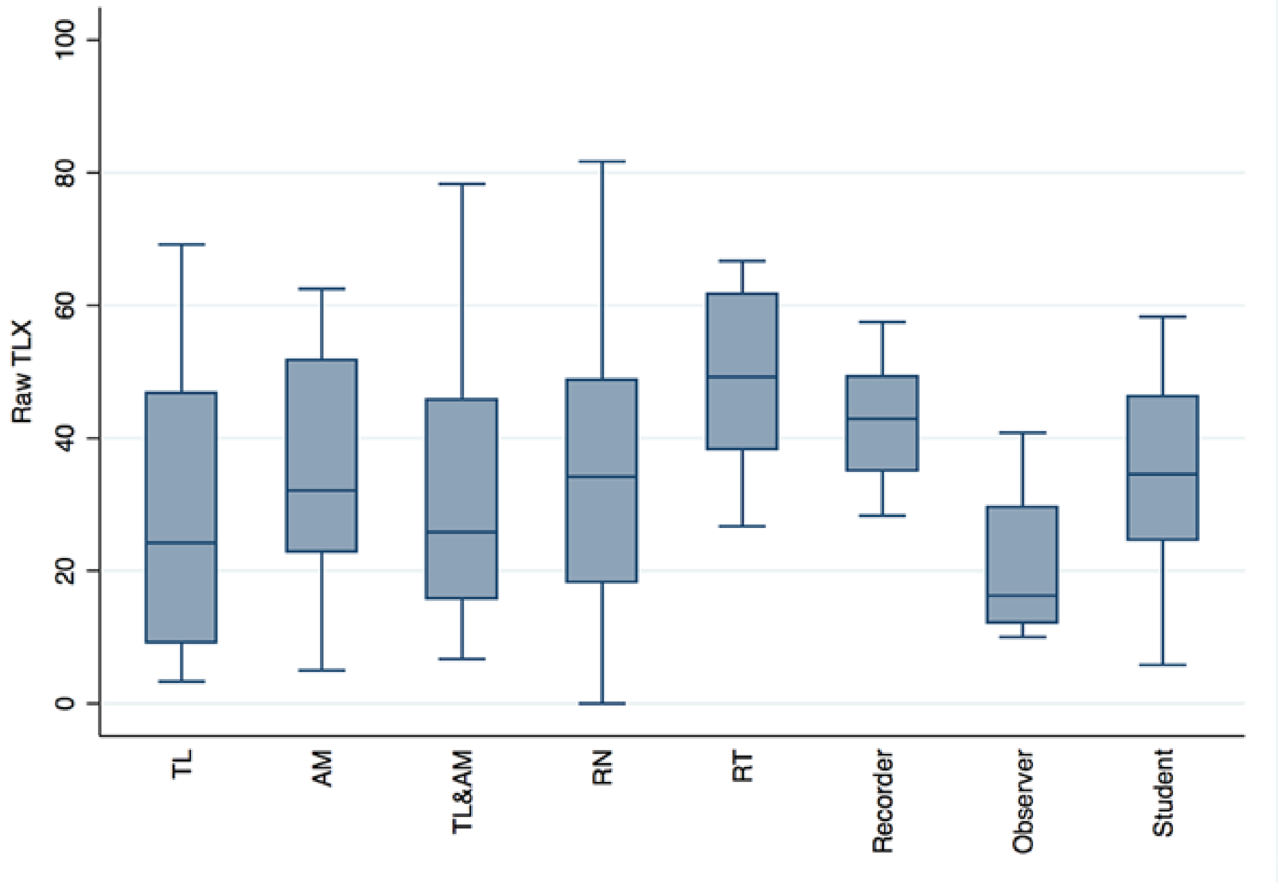


**Figure 4.3 Raw-TLX Scores by provider role in resuscitation.** Raw-TLX scores (y-axis) of healthcare providers A) by role during resuscitation TL – team lead, AM – airway manager, TL&AM – team lead and airway manager, RN – registered nurse, RT – respiratory therapist. Box plots represent median values (solid bar), IQR (margins of the box) and whiskers as a 95% confidence interval.



## 4.4 Parental Presence

Raw-TLX was lower when at least one parent was present 33(16-47) compared to when no parents were present 46(29-57) during the resuscitation (p=0.0004) (Figure 4.4). In subgroup analyses based on infants 5-minute Apgar scores, Raw-TLX was similar when parents were or were not present during resuscitation in both the low 5-minute Apgar group (≤3) (54(48-61) vs. 53(48-59) p=0.8103) and medium 5-minute Apgar group (4-7)(44 (36-54) vs. 49(42-58) p=0.7143). In the high 5-minute Apgar group (≥8) Raw-TLX was lower when parents were present compared to when they were not (23 (11-40) vs. 38 (24-56) p=0.0023) (Figure 4.5).

**Figure 4.4 Raw-TLX Scores by parental presence during resuscitations**. Raw-TLX Scores (y-axis) by parental presence during resuscitations. Box plots represent median values (solid bar), IQR (margins of the box) and whiskers as a 95% confidence interval.

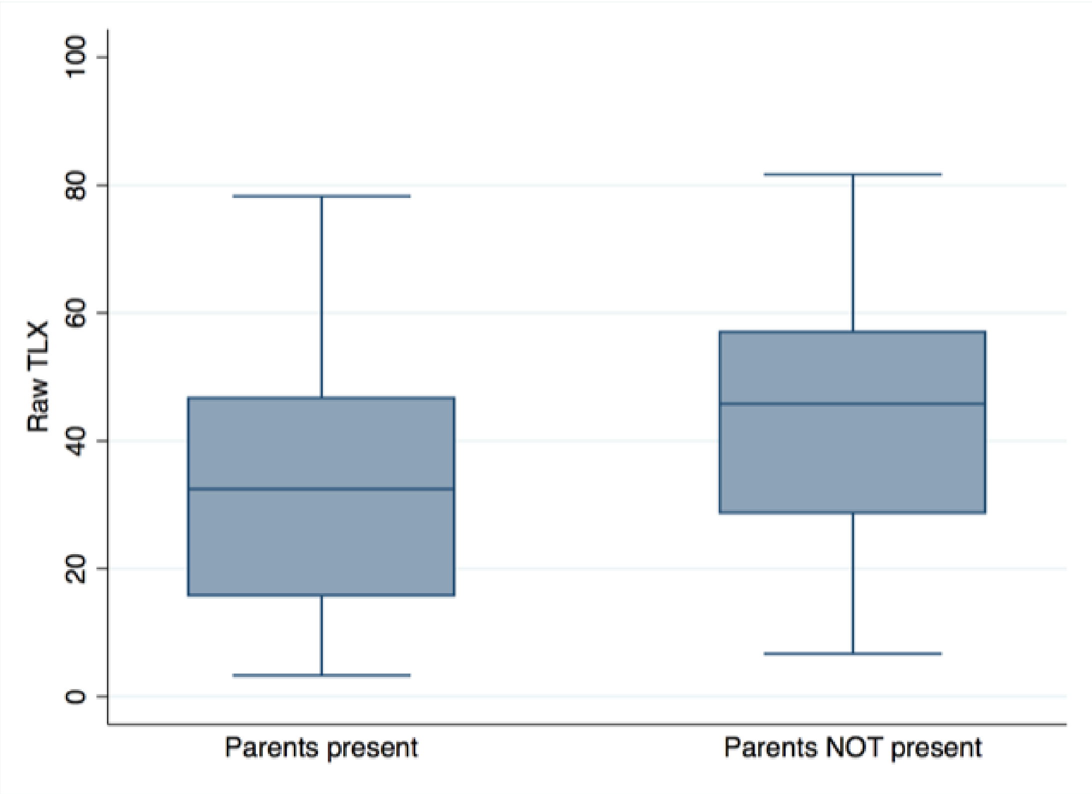
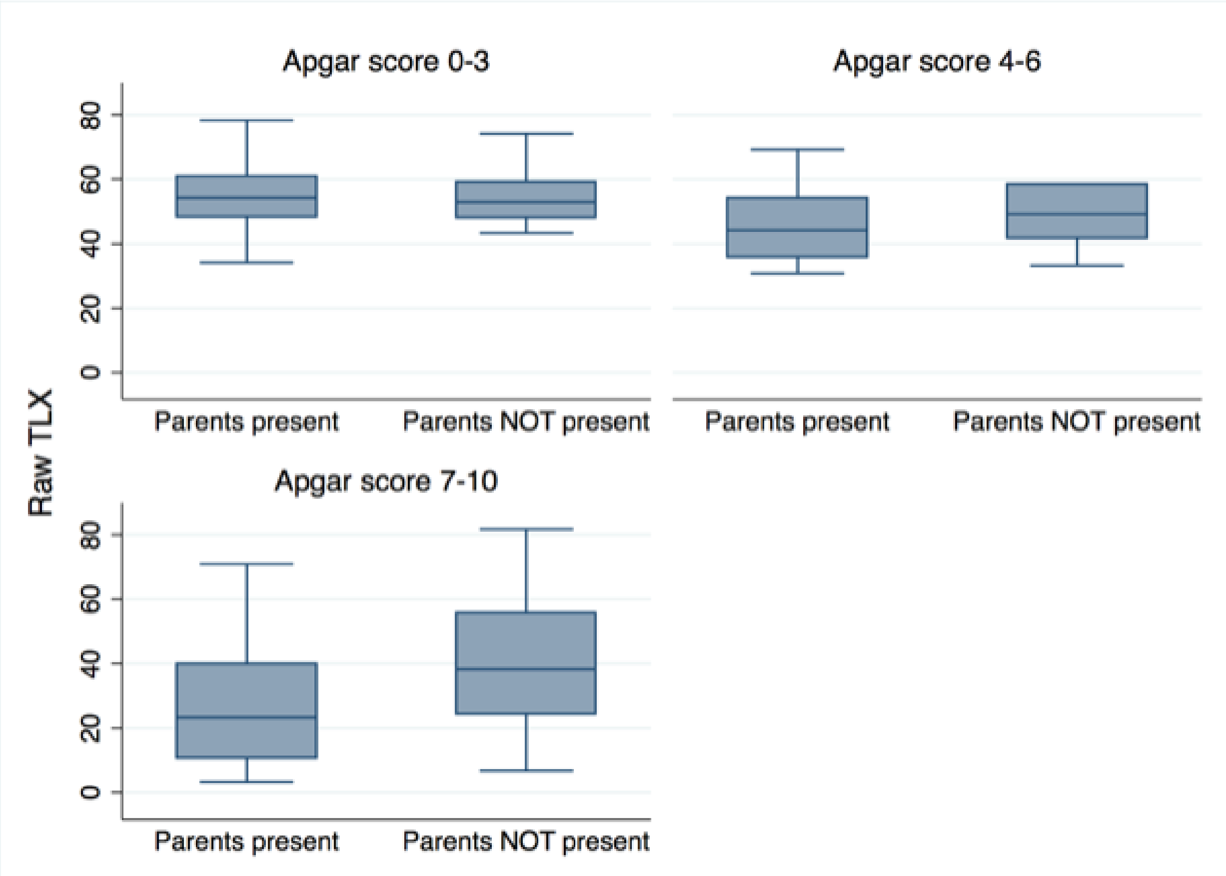


**Figure 4.5 Raw-TLX Scores by parental presence in resuscitations of infants with low, medium and high 5-minute Apgar scores.** Raw-TLX Scores (y-axis) by parental presence in resuscitations of infants with low, medium, and high 5-minute Apgar scores. Box plots represent median values (solid bar), IQR (margins of the box) and whiskers as a 95% confidence interval.



## 4.5 Limitations

By collecting surveys in an anonymous and self-administered manner, we were able to collect surveys 24 hours a day, which has been cited as a challenge in previous applications of NASA TLX in critical care settings[139]. However, this method of survey collection did not allow us to record the survey response rate or to assess workload distribution within teams. Additionally, recall bias might have resulted in inaccuracies in reporting of the performed interventions and their perceived workload. Although HCPs should have completed surveys immediately after returning from each delivery, due to the busy nature of the NICU, some of the surveys might have been completed several hours after the delivery room event. NASA TLX guidelines suggest that surveys be completed within 25 minutes of task completion; we do not know the exact timeframe in which HCPs completed each survey.

Furthermore, some HCPs might have only completed surveys for deliveries that they perceived to require a high workload, which may have limited the representativeness of our results. We do not have information about the length of time a parent was present or how many parents were present, which both may have affected our results. Finally, our analysis was limited by our inability to pair repeated survey responses by a single HCP due to the survey's anonymity. Therefore, each survey response was treated as an independent variable in our analysis, despite some HCPs completing several responses.

Caution should be taken to generalize this result into other delivery room settings, as workload is also dependent on available resources, social settings (i.e., safety culture), and participants' level of training. The participants in this study work in a high-risk delivery room setting and perform neonatal resuscitation tasks daily, which might have resulted in a lower level of workload compared to a novice group of HCPs or HCPs participating in resuscitations less frequently.

# Chapter 5. Discussion, Future Directions and Conclusions

This chapter consists of slightly modified sections from two articles, which are currently under peer-review i) "Does parental presence affect workload during neonatal resuscitation?" In Archives of Disease in Childhood - Fetal and Neonatal Edition, Zehnder E, Law B, Schmölzer GM. and ii) "Assessment of Healthcare Provider Workload in Neonatal Resuscitation" in PLOSOne, Zehnder E, Law B, Schmölzer GM

## 5.1 Discussion

In this thesis, I explored some aspects of cognitive ergonomics in neonatal resuscitation and demonstrated the feasibility of two methods not previously explored in this context.

### 5.1.1 Cognitive Processes During Neonatal Resuscitation

I described a novel method of examining HCPs' thought processes during delivery room resuscitation, which combined a retrospective think-aloud prompted by an own-point-of-view eye-tracked audio-visual recording with a semi-structured interview. Several interrelated themes were identified as the focus of HCPs discussions, including situation awareness, performance, working in teams, addressing threats to performance and perception of eye-tracking review. The key themes align with existing models of clinical reasoning, including those described in neonatal resuscitation.

Clinical reasoning described by our participants was guided by the collection of information from their environment, which underlies their working interpretation. The theme described here as situation awareness captures these processes and is in keeping with Endsley's concept of situation awareness (SA). SA can be defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future"[157].

Through our interviews, it was apparent that HCPs relied on both top-down and bottom-up processing when perceiving stimuli in their environment. They described relying on guidelines and pre-existing knowledge in combination with situational and social cues to guide their visual and audio attention and, therefore, perception during resuscitation. Similarly, comprehension and projection were largely informed by HCPs' experience and education. Endsley's model includes only that portion of knowledge that pertains to the state of a dynamic environment. Static information like established rules and pre-existing knowledge may influence the development of SA and how one acts in response to their developed SA but is not contained within the definition of SA[157]. Here we have described how HCPs developed and maintained an understanding of their situation as was described by participants; this included descriptions of how static information shaped perception, comprehension, and projections. Endsley suggests that SA is most important in domains requiring rapid information processing or those in which defective decision making can have significant implications[158]. Neonatal resuscitation meets both descriptions.

While we did not assess the accuracy of perceptions, comprehension, and projections in this project, previous work suggests that these are often inaccurate during neonatal resuscitation[111,159,160]. SA of HCPs during neonatal resuscitation was measured using a modified Situation Awareness Global Assessment Tool in a simulation study assessing the effect of monitor position. HCPs scored a median of 11 to 11.5 out of the possible 15 points on this measure with errors occurring in questions assessing perception and projection[110]. In assessments of HCPs' perceptions of chest rise and tidal volume during neonatal resuscitation, HCPs perceived values differed significantly from the actual values recorded. These results demonstrate the flawed perceptions of stimuli in clinical neonatal resuscitation[159,160]. Further, in an assessment of neonatologists and neonatal fellows' ability to predict the survival of extremely premature infants based on video recordings of clinical cases, observers' ability was poor[161].

Failures in developing and maintaining SA are detrimental to performance because SA guides decisions and actions. Decisions based on false or inaccurate SA can, therefore, lead to errors. Various factors can act as barriers to SA; Endsley refers to these as "SA demons"[162]. In the current study, HCPs described several factors that fall into the description of SA demons. The Requisite Memory Trap is a SA demon that refers to limits in size and duration of working memory and restricts an individual's ability to retain all situationally relevant information[162]. Some HCPs in our study described experiencing this as they discussed forgetting information that they identified as important earlier in the resuscitation (i.e., one HCP reported noticing that the suction catheter was an inappropriate size before the arrival of the infant but forgetting about this when the infant arrived because their working memory was more heavily tasked). Workload, anxiety, fatigue, and other stressors, also called WAFOS, are another group of SA demons; these factors degrade cognitive functioning such as working memory, cognitive processing, and attention, and therefore increase susceptibility to cognitive errors[162]. Various personal and situational factors discussed by HCPs in our study could be considered WAFOS, including i) hunger and frustration after a long stretch of working without a break, ii) task complexity during multiples deliveries or congenital abnormalities contributing to workload, iii) fatigue resulting from a busy day of work, feeling scrutinized by others in the resuscitation room, iv) lack of experience, and v) stress that the infant's heart rate was not increasing as expected. Similarly, stress and anxiety have been identified as a barrier to effective neonatal resuscitation in a population of Tanzanian midwives. The midwives reported that fear/anxiety affected the way they ventilate the baby (e.g., the technique of holding the bag and mask, skipping some steps of the guidelines) and result in delays during resuscitation[163]. We also observed evidence of another SA demon, misplaced salience. This was described as a distractor or distraction and involved stimuli that drew HCP attention away from important elements of the resuscitation. Though HCPs in this study described consciously working to prioritize information and stimuli to avoid this situation, potential distractors (identified in the recorded videos) included: i) irrelevant conversations between colleagues, ii) phone calls from the NICU or labour and delivery, iii) the resuscitation of other infants in the same room, and iv) unnecessary alarms. In simulated neonatal resuscitations, the distraction of HCPs during ventilation resulted in significantly altered ventilation parameters (e.g., inspiratory time, peak inflation pressure, and mean airway pressure)[164]. Distractors observed in resuscitations recorded in this project may have affected HCPs' performance or decision-making subconsciously.

Parental presence during neonatal resuscitation has been identified as a potential source of distraction to the healthcare team[106,108]. In a previous assessment of HCPs' perceptions of parental presence, some HCPs report that the father's presence makes them uneasy and adds to their already elevated stress. In contrast, others did not report any negative impact on their practice[108]. The perceptions of HCPs who participated in this study varied largely. HCP concerns about parental presence included worrying about how parents will cope, the extra demand that this may place on the health care team, and compromising the sterility of the room/procedure. Many HCPs reported that the presence of parents in the recorded resuscitation did not significantly impact their performance. However, some noted that this might have been different if the resuscitation did not go as planned.

Equipment difficulties also posed a threat to HCP development of SA as these difficulties often resulted in delayed physiological monitoring after birth, thereby delaying HCPs' perception of this information. These delays may be associated with delays in critical intervention and initiation of inappropriate interventions. HCPs also described the frustration they felt when monitoring equipment was delayed or seemingly inaccurate. Further, several HCPs mentioned that the addition of a sensor between the face mask and resuscitation device required for a respiratory function monitor was difficult or affected their mask positioning. Some HCPs felt that this additional sensor led them to place more pressure on the infant's face while providing PPV or CPAP. The sensor's additional length has been suggested as a drawback to this device previously and may negatively affect the usability of the ventilation device[165].

Effective team behaviour is critical in neonatal resuscitation, as was highlighted by the Joint Commission report, which identified HCP communication failure as the leading cause of neonatal death[4]. In our study, HCPs discussed various aspects of teamwork and communication, many of which have been identified and examined previously in neonatal resuscitation and other high-acuity team-based medical procedures. In a study of facilitators and barriers to effective teamwork during resuscitation in the NICU, many themes mirrored those in our study[166]. HCPs in this NICU resuscitation study reviewed a video-recorded simulated resuscitation and discussed team behaviours. Thinking out loud and sharing one's thoughts were both discussed by the participants as vital to effective resuscitation; this was similar to what was expressed by participants in our study. The importance of information sharing is further supported by a quantitative assessment of information sharing during simulated neonatal resuscitation. This analysis demonstrated that each additional use of information sharing behaviour (per minute) was associated with a 0.8% increase in a performance score and a 14-second decrease in resuscitation duration[167]. This study aligned with earlier work examining information sharing, which was summarized in a meta-analysis of 72 studies conducted within many disciplines, including business, medicine, and industry. The meta-analysis identified information sharing as a positive predictor of team performance, cohesion, decision satisfaction, and knowledge integration[168].

HCPs' willingness or hesitancy to speak up and provide feedback during neonatal resuscitation contributed to the working in teams theme described in this study. Assertive communication, or speaking up, has been shown to improve communication and reduce errors in a variety of healthcare settings[169,170]. During simulated neonatal resuscitation, each additional use of assertion (i.e., speaking up) was associated with a 41-second decrease in length of initial resuscitation and an increased performance score by 1.6%[167]. Even within our small sample of HCPs, the tendency to hold back or refrain from sharing criticism during neonatal resuscitation was described repeatedly. Factors that influence HCPs' decisions to speak up have been investigated in settings outside of neonatal resuscitation and include i) motivation to speak up (i.e., perceived risk to the patient), ii) lack of clarity, iii) personal relationship with other team members, iv) perceived attitudes of leaders, v) perceived safety and confidence based on experience, vi) education, and vii) communication skills[171]. Some of these factors were discussed by participants in this study. Hesitancy to speak up has been identified as an important contributing factor in human errors and adverse events[172]. Recently, O'Donovan *et al* conducted a systematic review of interventions and strategies that aimed to increase psychological safety (the shared belief held that a team is safe for interpersonal risk-taking) and speaking up behaviours in healthcare. This review found that interventions varied in efficacy, with some showing improvements in psychological safety and speaking up and others showing no improvements[173]. It may be beneficial to examine the efficacy of these interventions in the context of neonatal resuscitation.

Familiarity and trust within the healthcare team were discussed frequently as contributing to team performance among our participants. This dynamic seemed to contribute to HCPs' development of a shared mental model, as HCPs reported being familiar with each other's expectations and anticipated actions. They also reported being better able to communicate assertively when they were familiar with their team members. This reflects Zeynep *et al* findings that working synergistically is a facilitator to optimal team performance during neonatal resuscitation in the NICU. Synergy, as described in Zeynep *et al* study, required that HCPs had worked together previously and trusted each other. Further, they found that the addition of a new member with a different culture or a team that functioned with a steep hierarchy limited these feelings[166]. Theoretical studies of team familiarity suggest that it has a positive effect on team performance and increases perceptions of psychological safety[174].

Throughout the debrief process, HCPs reflected on their individual and team performance. HCPs reported on both reflections that occurred during the procedure (i.e., they noticed that something was or was not going well during the resuscitation) and during the video review (i.e., they noticed something was or was not going well after the fact when reviewing the recording). HCPs described points of reference from which they monitored performance compliance with guidelines, accord with clinical experience, comparison within and between teams, and infant response.

The NRP algorithm and hospital-specific adaptations were used by HCPs as a scaffold to guide actions and to measure performance. Adherence to the NRP algorithm has been examined in video recorded neonatal resuscitations; in these analyses, error rates ranged from 16-55% across studies [6,7,175]. Some protocol deviations cited frequently in the literature include inaccurate heart rate detection and delays in the initiation of appropriate interventions [175]. The causes of protocol deviations in neonatal resuscitation have received little attention in the literature. In this study, delays in the initiation of interventions were discussed by participants, who cited equipment difficulties and a lack of human resources as a contributing factor. Equipment difficulty, the inexperience of a colleague and time pressure were cited as factors that contributed to the administration of unnecessary interventions (e.g., a higher fraction of inspired oxygen than was required) in our study.

HCPs' clinical experience was described as contributing to decision making. HCPs also relied on their experience to evaluate their actions during resuscitations (e.g., whether their actions prioritized elements of care, they effectively problem-solved when challenges arose and optimized the use of the material and team resources). HCP inexperience has been associated with prolonged inspiratory times when using a T-piece resuscitator for neonatal resuscitation[164]. In adult resuscitation, a CTA augmented by eye-tracking recording found expert performance to be marked by logistic awareness, managing uncertainty, visual fixation behaviours, selective attendance to information, and anticipatory behaviours[112].

HCPs' perceptions of the infant's response to intervention seemed to be another metric against which HCPs monitored their performance during resuscitation. This was the case during the resuscitation when HCPs were continuously monitoring the infant's response to recent interventions and optimizing their strategy accordingly. Infant response to interventions was also heavily considered during HCPs' reviews of overall performance during the video debrief.

During the video debrief, each HCP demonstrated metacognitive skills, an awareness of their cognitive processes. The quality of data obtained in this study is dependent on the accuracy and completeness of their metacognition (i.e., recall of specific cognitive processes during video debrief). Though insights into one's specific cognitive processes are known to be limited both in accuracy and completeness when asked retrospectively, video review may minimize these limitations[126,176]. Further, own-point-of-view video along with eye-tracked data overlay may add specificity in tasks in which own-point-of-view recording is not sufficiently detailed (i.e., does not as closely reflect changes in visual attention). Own-point-of-view recordings may also allow for greater psychological immersion than recordings created with external cameras as they better convey the focus of participants' attention during the task. These recordings promote the sharing of emotional experiences and reminiscence[126].

HCPs in this study all agreed that the presence of the eye-tracked own-point-of-view recording allowed them to recall better their actions and cognitive processes that occurred during resuscitation. Participants paused video frequently during the debriefing to expand on their thoughts or reasoning at a given point, allowing for a depth of information and explanation that would likely not have surfaced if the think-aloud was conducted concurrently. One HCP did report feeling an increased sense of pressure due to their awareness that they were being recorded by the eye-tracked glasses; this may have influenced their performance or experience of the resuscitation.

Some HCPs explained that this was an interesting learning opportunity for themselves, allowing them to reflect on their performance in a new way. Several HCPs also suggested that this should be explored as a training mechanism. Video debriefing has been used previously in neonatal resuscitation education with mixed results. Skåre *et al* demonstrated improved adherence to the neonatal resuscitation algorithm and improved performance in both technical and non-technical skills of neonatal HCPs after implementation of video-assisted, performance-focused debriefings[177]. Campbell and Finan found no improvements in neonatal resuscitation algorithm compliance following video-debriefing of inter-professional teams in simulated neonatal resuscitation. HCPs who participated in this study felt as though this training intervention was beneficial[178]. Own-point-of-view video debrief may provide a different experience to learners and should be explored as a training mechanism in neonatal resuscitation.

### 5.1.2 Subjective Workload of Healthcare Providers During Neonatal Resuscitation

As was apparent through our CTA study, HCPs are tasked with many cognitive and physical demands during neonatal resuscitation. These demands contribute to HCPs' workload during neonatal resuscitation. Workload refers to the cost to a human operator of completing a task, and is not only related to the objective requirements of the task, but is also affected by the circumstances surrounding task completion along with the skills, behaviours, and perception of the operator[62]. If the workload of a task becomes too great, delays and errors become more likely, and human costs such as fatigue, stress, and illness may reach an unacceptable level[63,64,179]. Excess workload in health care can compromise the quality and safety of patient care[63,180].

To optimally manage workload in neonatal resuscitation, it may be beneficial to first understand how workload is distributed and what factors increase or decrease individual and team experience of workload. We used NASA-TLX to evaluate HCPs' perceived workload and to determine the relationship between roles, the acuity of care, parental presence and perceived workload during neonatal resuscitation in the delivery room.

This was the first study using the NASA TLX to examine the workload of HCPs during neonatal resuscitation in the delivery room. The overall workload varied largely within roles but was similar between roles (Figure 4.3). However, there was a significantly increased overall workload when HCPs cared for infants with lower 5-minute Apgar scores or with escalating delivery room interventions (Figure 4.2 A-D). Additionally, overall workload tended to be lower when parents were present during resuscitation compared to when parents were not present.

NASA TLX is a subjective measure of workload that has been validated in medicine (i.e., intensive care unit nurses and pediatric trauma resuscitations), aeronautics, psychology, and driving[105,139,181]. A meta-analysis reported the NASA TLX scores for many task types, including medicine, sport, aeronautic, and psychology and reported a mean (SD) overall workload score of 45 (15) in all tasks[182]. In this meta-analysis, Grier also performed a subgroup analysis of only medical tasks. The median (IQR) reported NASA TLX global score for these medical tasks was 50.6 (39-61). NASA TLX global scores in this meta-analysis were calculated in two different ways (Raw-TLX as calculated in this study and a weighted scoring system), which have been shown to correlate closely[182]. The overall Raw-TLX score in our study was 34 (18-49), which may suggest that this task is associated with a lower perceived workload than other medical tasks. These differences may be due to the demands of the task, resources available in our institution, or experience level of our participants. Additionally, the objective task demands of delivery room events included in this study varied largely from no intervention to complex and high-pressure interventions (e.g., intubation and chest compression). This degree of variability in task difficulty potentially exceeds that of other medical tasks.

The paper and pencil NASA TLX survey was simple, convenient, and rapidly completed by respondents. We have demonstrated the feasibility of NASA TLX and supported its validity in HCPs participating in neonatal delivery room care as Raw-TLX increased significantly with the complexity of care required, as expected. Raw-TLX was significantly higher in HCPs who attended the delivery of infants with low 5-minute Apgar scores 54 (48-61), compared to infants with medium (IQR) 38 (30-48) or high 25 (13- 40) 5-minute Apgar scores. Furthermore, we found a significantly higher perceived workload for HCPs who attended deliveries of infants who required any delivery room intervention compared to no delivery room intervention (Figure 4.2 A). PPV, intubation, and chest compression were all variables, which significantly increased the perceived workload (Figure 4.2 B-D). These findings suggest that HCPs experience higher workload with an increased level of care, which might be due to increased i) objective task demands, ii) perception of the need for rapid interventions, and iii) perceived significance of potential consequences of delays or errors. Furthermore, HCPs might have had less experience participating in high-level resuscitations (high acuity, low occurrence events), which might have added to the perceived workload.

The overall workload varied largely within the assigned role during delivery room care but was similar between assigned roles (Figure 4.3). This suggests that workload during delivery room care was similar between team members among the health care team, or it could reflect a too low sample size due to a large number of different roles. Interestingly, HCPs who acted as team lead + airway manager reported similar Raw-TLX scores to HCPs who acted as either team leader or airway manager despite holding two roles simultaneously. This held true even when we controlled/adjusted for Apgar score/number of interventions applied. The similar Raw-TLX score might reflect less role confusion and therefore decreased the demands on the combined role and should be explored further. However, Toil *et al* reported that the team leader perceives a greater workload compared to their team during simulated sepsis scenario[140], while Geis *et al* observed that medication nurses perceived greater workload than their team members during simulated pediatric resuscitations[183]. Understanding the workload distribution between team members and its effect on each team member's performance will allow us to design targeted interventions to improve equitable role assignment and workload management.

This was the first study to examine the relationship between parental presence and HCPs' experience of workload in neonatal resuscitation. HCPs' perception of workload was lower when at least one family member was present during delivery room care compared to no parent(s) present. In a subgroup analysis based on infants' 5-minute Apgars, a similar overall workload between parental present and not present in the low and medium Apgar groups was observed. Interestingly, HCPs had significantly lower overall workload when the parent(s) were present during resuscitations with high 5-minute Apgar scores (Figure 4.5). This suggests that concerns that parental presence would increase workload appear unfounded.

Qualitative studies examining HCPs' perception of parental presence suggest that HCPs tend to support parental presence based on perceived benefit to the parent(s). But concerns about parents' presence affecting HCPs' stress and performance during neonatal resuscitation have been reported[106,108]. A qualitative interview study with HCPs who participate in delivery room care reported variability in HCPs' perception of the father's presence during neonatal delivery. Some HCPs report that the fathers' presence makes them uneasy and adds to their already elevated stress, while others did not report any negative impact on their practice[108]. Furthermore, parents who have witnessed the resuscitation of their child at birth or later in life reported concerns that their presence added to the pressure on HCPs[106]. The limited data about the impact of parental presence during neonatal resuscitation this suggests that HCPs increased efforts to maintain a calm and self-assured manner in hopes that this attitude would comfort the parent(s)[108]. During pediatric resuscitation, HCPs reported benefits including i) feeling more appreciated, ii) acting more professionally, iii) increased rapport between HCPs and family members, resulting in a more humanistic experience[184].

We did not measure the objective task demands of HCPs during neonatal resuscitation. Therefore, we can only speculate that these demands would be greater when babies' parent(s) are present compared to when parents are not present. HCPs may be burdened with comforting parents, providing parents with information about their baby's care, and ensuring that parents do not interfere with resuscitative care. We speculate that this increase in task demand might be offset by HCPs' increased efforts to maintain a calm, professional and self-assured manner, and an increased sense of appreciation.

## 5.2 Future Directions

A better understanding of the cognitive processes that drives performance in neonatal resuscitation may allow for optimization of the I) physical space in which resuscitation takes place, II) usability of resuscitation equipment, and III) applicability of training and assessment. Applications of methods described in this thesis may be beneficial in enhancing this understanding.

One example of how cognitive ergonomics may inform clinical practice in neonatal resuscitation is the ongoing assessments of newer additional monitoring equipment including respiratory function monitors and near-infrared spectroscopy in the delivery room[185,186]. While these monitors may allow HCPs to be better informed of patient status, they may also add cognitive and physical demand to HCPs using them. Cognitive ergonomic methods such as those described in this thesis may provide insight into these additional demands and potential challenges that they may pose. Respiratory function monitors were used in some of the resuscitations recorded in our project. During debriefs, HCPs who used these devices mentioned that the additional length from the flow sensor required for the respiratory function monitor caused them to place too much pressure on the infant's face and therefore compromised their performance. This is an example of an unintended consequence of additional equipment that may be identified and mitigated through the design of equipment or implementation of education programs that train users on how to best address these challenges.

Further, eye-tracking debriefs may be beneficial as a training and assessment tool in neonatal resuscitation. This method has been applied in clinical simulations[187,188], and their routine use during neonatal resuscitation should be examined and might provide an immersive learning experience. As an assessment tool, debriefing of eye-tracked performance in a simulation or clinical resuscitation with an instructor or assessor may reveal shortcomings in reasoning and decision making which would not be apparent from observing behaviours alone.

NASA-TLX could be used to better understand how workload varies between institutions and within teams during neonatal resuscitation. This knowledge could be used to inform staffing guidelines and optimized task assignments to promote equitable role assignments. The shortened version of the NASA-TLX survey (which does not include the weighting portion) may be used in future studies as this was confusing and time-consuming for participants in our study and maybe unnecessary[145].

Finally, the effects of parental presence on HCPs' experience of and performance in neonatal resuscitation should be further evaluated. In this thesis, I explored the effect of parental presence on HCPs' subjective workload and described how parental presence is integrated into the cognitive processes of a small sample of HCPs. An assessment of objective performance outcomes is warranted.

## 5.3 Conclusions

Neonatal resuscitation is a high pressure and time-sensitive procedure that requires HCPs to address many cognitive and physical demands. I explored the cognitive processes of a group of HCPs who participate in neonatal resuscitations. I also described HCPs' experiences of workload in neonatal resuscitation. These projects demonstrated how two methods from cognitive ergonomics could be applied to neonatal resuscitation. Future research should assess targeted components of HCPs' cognition in neonatal resuscitation and identify threats to technical and non-technical performance. Interventions may be developed to address these threats, thereby improving the effectiveness of neonatal resuscitation.

## References


1. Aziz K, Chadwick M, Baker M, Andrews W. Ante- and intra-partum factors that predict increased need for neonatal resuscitation. *Resuscitation*. 2008;79(3):444-452. doi:10.1016/j.resuscitation.2008.08.004
2. Linsell L, Johnson S, Wolke D, et al. Cognitive trajectories from infancy to early adulthood following birth before 26 weeks of gestation: A prospective, population-based cohort study. *Arch Dis Child*. 2018;103(4):363-370. doi:10.1136/archdischild-2017-313414
3. Rees S, Harding R, Walker D. The biological basis of injury and neuroprotection in the fetal and neonatal brain. *Int J Dev Neurosci*. 2011;29(6):551-563. doi:10.1016/j.ijdevneu.2011.04.004
4. The Joint Commission. *Sentinel Event Alert: Preventing Infant Death and Injury during Delivery*.; 2004. doi:10.1002/poc...Journal
5. Yamada NK, Kamlin COF, Halamek LP. Optimal human and system performance during neonatal resuscitation. *Semin Fetal Neonatal Med*. 2018;23(5):306-311. doi:10.1016/j.siny.2018.03.006
6. Carbine DN, Finer NN, Knodel E, Rich W. Video recording as a means of evaluating neonatal resuscitation performance. *Pediatrics*. 2000;106(4 I):654-658. doi:10.1542/peds.106.4.654
7. Thomas EJ, Sexton JB, Lasky RE, Helmreich RL, Crandell DS, Tyson J. Teamwork and quality during neonatal care in the delivery room. *J Perinatol*. 2006;26(3):163-169. doi:10.1038/sj.jp.7211451
8. Yamada NK, Yaeger KA, Halamek LP. Analysis and classification of errors made by teams during neonatal resuscitation. *Resuscitation*. 2015;96:109-113. doi:10.1016/j.resuscitation.2015.07.048
9. Schraagen JM, Chipman SF, Shalin VL. *Cognitive Task Analysis*. Mahwah, NJ: L. Erlbaum Associates; 2000.
10. Clark R, Feldon D, Merrienboer JJ van, Yates K, Early S. Cognitive task analysis. In: Spector JM, Merrill MD, van Merrienboer JJG, Driscoll MP, eds. *Handbook of Research on Educational Communications and Technology*. 3rd ed. Macmillan/Gale; 2008:577-593.
11. Cooke NJ, J. N. Varieties of knowledge elicitation techniques. *Int J Hum Comput Stud*. 1994;41(6):801-849. doi:10.1006/ijhc.1994.1083
12. Pickup L, Lang A, Shipley L, et al. Development of a clinical interface for a novel newborn resuscitation device: Human factors approach to understanding cognitive user requirements. *J Med Internet Res*. 2019;21(6). doi:10.2196/12055

13. Militello LG, Hutton RJB. Applied cognitive task analysis (ACTA): a practitioner's toolkit for understanding cognitive task demands. *Ergonomics*. 1998;41(11):1618-1641. doi:10.1080/001401398186108
14. Li H, Ku M, Schumacher R, Seagull FJ. Designing automated aids for patient monitoring systems in intensive care units. *Proc Int Symp Hum Factors Ergon Heal Care*. 2013;2(1):69-76. doi:10.1177/2327857913021014
15. Ferris TK, Shepley MM. The design of neonatal incubators: A systems-oriented, human-centered approach. *J Perinatol*. 2013;33(Suppl.1):S24-S31. doi:10.1038/jp.2013.11
16. Kawamoto K, Houlihan CA, Balas EA, Lobach DF. Improving clinical practice using clinical decision support systems: a systematic review of trials to identify features critical to success. *BMJ*. 2005;330(7494):765. doi:10.1136/bmj.38398.500764.8F
17. Leppink J, van den Heuvel A. The evolution of cognitive load theory and its application to medical education. *Perspect Med Educ*. 2015;4(3):119-127. doi:10.1007/s40037-015-0192-x
18. Fuerch JH, Yamada NK, Coelho PR, Lee HC, Halamek LP. Impact of a novel decision support tool on adherence to Neonatal Resuscitation Program algorithm. *Resuscitation*. 2015;88:52-56. doi:10.1016/j.resuscitation.2014.12.016
19. Schnittker R, Marshall S., Horberry T, Young K, Lintern G. Examination of anesthetic practitioners' decisions for the design of a cognitive tool for airway management. *Proc Hum Factors Ergon Soc Annu Meet*. 2016;60(1):1765-1769. doi:10.1177/1541931213601404
20. Schnittker R, Marshall S, Horberry T, Young KL. *The Co-Design Process of a Decision Support Tool for Airway Management*. Springer Nature; 2018. doi:10.1007/978-3-319-96098-2_16
21. Klein GA, Calderwood R, MacGregor D. Critical decision method for eliciting knowledge. *IEEE Trans Syst Man Cybern*. 1989;19(3):462-472. doi:10.1109/21.31053
22. Shibl R, Lawley M, Debuse J. Factors influencing decision support system acceptance. *Decis Support Syst*. 2013;54(2):953-961. doi:10.1016/j.dss.2012.09.018
23. Baxter GD, Monk AF, Tan K, Dear PRF, Newell SJ. Using cognitive task analysis to facilitate the integration of decision support systems into the neonatal intensive care unit. *Artif Intell Med*. 2005;35(3):243-257. doi:10.1016/j.artmed.2005.01.004
24. Sheehan B, Kaufman D, Bakken S, Currie LM. Cognitive analysis of decision support for antibiotic ordering in a neonatal intensive care unit. *Appl Clin Inform*. 2012;03(01):105-123. doi:10.4338/ACI-2011-10-RA-0060
25. Polson P, Lewis C, Rieman J, Man CW-IJ of, 1992 U. Cognitive walkthroughs: a method for theory-based evaluation of user interfaces. *Int J Man Mach Stud*. 1992;36(5):741-773.
26. Someren M Van, Barnard Y, Sandberg J. *The Think Aloud Method: A Practical Approach to*

*Modelling Cognitive*. London: Academic Press; 1994.
27. Manser T. Teamwork and patient safety in dynamic domains of healthcare: a review of the literature. *Acta Anaesthesiol Scand*. 2009;53(2):143-151. doi:10.1111/j.1399-6576.2008.01717.x
28. McHugh A, Crandall B, Miller T. Barriers and facilitators of common ground in critical care teams. *Proc Hum Factors Ergon Soc Annu Meet*. 2006;50(10):934-938. doi:10.1177/154193120605001029
29. Custer JW, White E, Fackler JC, et al. A qualitative study of expert and team cognition on complex patients in the pediatric intensive care unit. *Pediatr Crit Care Med*. 2012;13(3):278-284. doi:10.1097/PCC.0b013e31822f1766
30. Schraagen JM, Schouten T, Smit M, et al. Assessing and improving teamwork in cardiac surgery. *Qual Saf Health Care*. 2010;19(6):e29. doi:10.1136/qshc.2009.040105
31. Sadideen H, Wilson D, Moiemen N, Kneebone R. Proposing "The Burns Suite" as a novel simulation tool for advancing the delivery of burns education. *J Burn Care Res*. 2014;35(1):62-71. doi:10.1097/BCR.0b013e31829b371d
32. Elen, Jan.Clark RE. When less is more: research and theory insights about instruction for complex learning. In: *Handling Complexity in Learning Environments : Theory and Research*. 1st ed. Oxford, UK ; Elsevier; 2006:287-288.
33. Sullivan ME, Yates KA, Inaba K, Lam L, Clark RE. The use of cognitive task analysis to reveal the instructional limitations of experts in the teaching of procedural skills. *Acad Med*. 2014;89(5):811-816. doi:10.1097/ACM.0000000000000224
34. Clark R. Cognitive Task Analysis for Expert-Based Instruction in Healthcare. In: *Handbook of Research on Educational Communications and Technology*. New York, NY: Springer New York; 2014:541-551. doi:10.1007/978-1-4614-3185-5_42
35. Tofel-Grehl C, Feldon DF. Cognitive task analysis–based training. *J Cogn Eng Decis Mak*. 2013;7(3):293-304. doi:10.1177/1555343412474821
36. Wingfield LR, Kulendran M, Chow A, Nehme J, Purkayastha S. Cognitive task analysis bringing olympic athlete style training to surgical education. *Surg Innov*. 2015;22(4):406-417. doi:10.1177/1553350614556364
37. Crandall B, Getchell-Reiter K. Critical decision method: a technique for eliciting concrete assessment indicators from the intuition of NICU nurses. *ANS Adv Nurs Sci*. 1993;16(1):42-51. doi:10.1097/00012272-199309000-00006
38. Militello L, Nursing L. Patient assessment skills: assessing early cues of necrotizing enterocolitis. *J Perinat Neonatal Nurs*. 1995;9(2):42-52. doi:10.1097/00005237-199509000-

00007
39. Patterson MD, Militello LG, Bunger A, et al. Leveraging the critical decision method to develop simulation-based training for early recognition of sepsis. *J Cogn Eng Decis Mak*. 2016;10(1):36-56. doi:10.1177/1555343416629520
40. Mileder LP, Urlesberger B, Szyld EG, Roehr CC, Schmölzer GM. Simulation-based neonatal and infant resuscitation teaching: A systematic review of randomized controlled trials. *Klin Padiatr*. 2014;226(5):259-267. doi:10.1055/s-0034-1372621
41. Cusack J, Fawke J. Neonatal resuscitation: are your trainees performing as you think they are? A retrospective review of a structured resuscitation assessment for neonatal medical trainees over an 8-year period. *Arch Dis Child Fetal Neonatal Ed*. 2012;97(4):F246-8. doi:10.1136/archdischild-2011-300548
42. Cannon-Bowers J, Bowers C, Stout R, Ricci K, Hildabrand A. Using cognitive task analysis to develop simulation-based training for medical tasks. *Mil Med*. 2013;178(10S):15-21. doi:10.7205/MILMED-D-13-00211
43. Masiello I. Why simulation-based team training has not been used effectively and what can be done about it. *Adv Heal Sci Educ*. 2012;17(2):279-288. doi:10.1007/s10459-011-9281-8
44. Pfandler M, Stefan P, Wucherer P, Lazarovici M, Weigl M. Stepwise development of a simulation environment for operating room teams: the example of vertebroplasty. *Adv Simul*. 2018;3(1):18. doi:10.1186/s41077-018-0077-2
45. Nimmo GR, Wylie G, Scarth J, et al. Critical events simulation for neonatal and paediatric extracorporeal membrane oxygenation. *J Intensive Care Soc*. 2008;9(1):20-22. doi:10.1177/175114370800900107
46. Sawyer T, Burke C, McMullan DM, et al. Impacts of a pediatric extracorporeal cardiopulmonary resuscitation (ECPR) simulation training program. *Acad Pediatr*. January 2019. doi:10.1016/J.ACAP.2019.01.005
47. Flin R, Yule S, Paterson-Brown S, Maran N, Rowley D, Youngson G. Teaching surgeons about non-technical skills. *Surg*. 2007;5(2):86-89. doi:10.1016/s1479-666x(07)80059-x
48. Buist M, Harrison J, Abaloz E, Van Dyke S. Six year audit of cardiac arrests and medical emergency team calls in an Australian outer metropolitan teaching hospital. *BMJ*. 2007;335(7631):1210-1212. doi:10.1136/bmj.39385.534236.47
49. Yamada NK, Halamek LP. On the need for precise, concise communication during resuscitation: a proposed solution. *J Pediatr*. 2015;166(1):184-187. doi:10.1016/j.jpeds.2014.09.027
50. Fletcher G, Flin R, McGeorge P, Glavin R, Maran N, Patey R. Rating non-technical skills:

developing a behavioural marker system for use in anaesthesia. *Cogn Technol Work*. 2004;6(3):165-171. doi:10.1007/s10111-004-0158-y

51. Flin R, Fletcher G, McGeorge P, Glavin R, Maran N, Patey R. Rating anaesthetists' non-technical skills — The Ants System. *Proc Hum Factors Ergon Soc Annu Meet*. 2003;47(12):1498-1501. doi:10.1177/154193120304701227

52. Yule S, Flin R, Paterson-Brown S, Maran N, Rowley D. Development of a rating system for surgeons' non-technical skills. *Med Educ*. 2006;40(11):1098-1104. doi:10.1111/j.1365-2929.2006.02610.x

53. Boet S, Larrigan S, Martin L, Liu H, Sullivan KJ, Etherington N. Measuring non-technical skills of anaesthesiologists in the operating room: a systematic review of assessment tools and their measurement properties. *Br J Anaesth*. 2018;121(6):1218-1226. doi:10.1016/J.BJA.2018.07.028

54. Cavicchiolo ME, Cavallin F, Staffler A, et al. Decision making and situational awareness in neonatal resuscitation in low resource settings. *Resuscitation*. 2019;134(4):41-48. doi:10.1016/j.resuscitation.2018.10.034

55. Szulewski A, Braund H, Egan R, et al. Starting to think like an expert: an analysis of resident cognitive processes during simulation-based resuscitation examinations. *Ann Emerg Med*. 2019;74(5):647-659. doi:10.1016/J.ANNEMERGMED.2019.04.002

56. D'Angelo A-LD, Rutherford DN, Ray RD, et al. Idle time: an underdeveloped performance metric for assessing surgical skill. *Am J Surg*. 2015;209(4):645-651. doi:10.1016/J.AMJSURG.2014.12.013

57. Kyaw Tun J, Granados A, Mavroveli S, et al. Simulating various levels of clinical challenge in the assessment of clinical procedure competence. *Ann Emerg Med*. 2012;60(1):112-120.e5. doi:10.1016/J.ANNEMERGMED.2012.01.036

58. D'Angelo A-LD, Cohen ER, Kwan C, et al. Use of decision-based simulations to assess resident readiness for operative independence. *Am J Surg*. 2015;209(1):132-139. doi:10.1016/J.AMJSURG.2014.10.002

59. de Vries AH, Muijtjens AMM, van Genugten HGJ, et al. Development and validation of the TOCO–TURBT tool: a summative assessment tool that measures surgical competency in transurethral resection of bladder tumour. *Surg Endosc*. 2018;32(12):4923-4931. doi:10.1007/s00464-018-6251-8

60. Law BHY, Cheung P-Y, Wagner M, van Os S, Zheng B, Schmölzer G. Analysis of neonatal resuscitation using eye tracking: a pilot study. *Arch Dis Child Fetal Neonatal Ed*. 2018;103(1):F82-F84. doi:10.1136/archdischild-2017-313114

61. Young MS, Brookhuis KA, Wickens CD, Hancock PA. State of science: mental workload in ergonomics. *Ergonomics*. 2015;58(1):1-17. doi:10.1080/00140139.2014.956151
62. Hart SG, Staveland LE. Development of NASA-TLX (Task Load Index): results of empirical and theoretical research. *Adv Psychol*. 1988;52:139-183. doi:10.1016/S0166-4115(08)62386-9
63. Tubbs-Cooley HL, Mara CA, Carle AC, Mark BA, Pickler RH. Association of nurse workload with missed nursing care in the neonatal intensive care unit. *JAMA Pediatr*. 2019;173(1):44. doi:10.1001/jamapediatrics.2018.3619
64. Bagheri Hosseinabadi M, Khanjani N, Etemadinezhad S, Samaei SE, Raadabadi M, Mostafaee M. The associations of workload, individual and organisational factors on nurses' occupational injuries. *J Clin Nurs*. 2019;28(5-6):902-911. doi:10.1111/jocn.14699
65. Desmond PA, Hoyes TW. Workload variation, intrinsic risk and utility in a simulated air traffic control task: Evidence for compensatory effects. *Saf Sci*. 1996;22(1-3):87-101. doi:10.1016/0925-7535(96)00008-2
66. Robert G, Hockey J. Compensatory control in the regulation of human performance under stress and high workload: A cognitive-energetical framework. *Biol Psychol*. 1997;45(1-3):73-93. doi:10.1016/S0301-0511(96)05223-4
67. Matthews G, Davies DR. Individual differences in energetic arousal and sustained attention: a dual-task study. *Pers Individ Dif*. 2001;31(4):575-589. doi:10.1016/S0191-8869(00)00162-8
68. Needleman J, Buerhaus P, Mattke S, Stewart M, Zelevinsky K. Nurse-staffing levels and the quality of care in hospitals. *N Engl J Med*. 2002;346(22):1715-1722. doi:10.1056/NEJMsa012247
69. Cho SH, Ketefian S, Barkauskas VH, Smith DG. The effects of nurse staffing on adverse events, morbidity, mortality, and medical costs. *Nurs Res*. 2003;52(2):71-79. doi:10.1097/00006199-200303000-00003
70. Giraud T, Dhainaut JF, Vaxelaire JF, et al. Iatrogenic complications in adult intensive care units: A prospective two- center study. *Crit Care Med*. 1993;21(1):40-51. doi:10.1097/00003246-199301000-00011
71. Tourgeman-Bashkin O, Shinar D, Zmora E. Causes of near misses in critical care of neonates and children. *Acta Paediatr Int J Paediatr*. 2008;97(3):299-303. doi:10.1111/j.1651-2227.2007.00616.x
72. Duffield C, Diers D, O'Brien-Pallas L, et al. Nursing staffing, nursing workload, the work environment and patient outcomes. *Appl Nurs Res*. 2011;24(4):244-255. doi:10.1016/j.apnr.2009.12.004
73. Tierney SJ, Seymour-Route P, Crawford S. Weighted staffing plans for better prediction of

staffing needs. *J Nurs Adm*. 2013;43(9):461-467. doi:10.1097/NNA.0b013e3182a23e41

74. Fatimah Al-Kandari, Deepa Thomas. Perceived adverse patient outcomes correlated to nurses' workload in medical and surgical wards of selected hospitals in Kuwait. *J Clin Nurs*. 2009;18(4):581-590. doi:10.1111/j.1365-2702.2008.02369.x

75. Paas FGWC, van Merriënboer JJG, Adam JJ. Measurement of Cognitive Load in Instructional Research. *Percept Mot Skills*. 1994;79(1):419-430. doi:10.2466/pms.1994.79.1.419

76. De Rivecourt M, Kuperus MN, Post WJ, Mulder LJM. Cardiovascular and eye activity measures as indices for momentary changes in mental effort during simulated flight. *Ergonomics*. 2008;51(9):1295-1319. doi:10.1080/00140130802120267

77. Fournier, Wilson S. Electrophysiological, behavioral, and subjective indexes of workload when performing multiple tasks: manipulations of task difficulty and training. *Int J Psychophysiol*. 1999;31(2):129-145. doi:10.1016/s0167-8760(98)00049-x

78. Finsen L, Søgaard K, Jensen C, Borg V, Christensen H, Ségaard K. Muscle activity and cardiovascular response during computer-mouse work with and without memory demands. *Ergonomics*. 2010;44(14):1312-1329. doi:10.1080/00140130110099065

79. Reyes del Paso GA, Langewitz W, Mulder LJM, van Roon A, Duschek S. The utility of low frequency heart rate variability as an index of sympathetic cardiac tone: A review with emphasis on a reanalysis of previous studies. *Psychophysiology*. 2013;50(5):477-487. doi:10.1111/psyp.12027

80. Rieger A, Stoll R, Kreuzfeld S, Behrens K, Weippert M. Heart rate and heart rate variability as indirect markers of surgeons' intraoperative stress. *Int Arch Occup Environ Health*. 2014;87(2):165-174. doi:10.1007/s00420-013-0847-z

81. Rieger A, Fenger S, Neubert S, Weippert M, Kreuzfeld S, Stoll R. Psychophysical workload in the operating room: primary surgeon versus assistant. *Surg Endosc*. 2015;29(7):1990-1998. doi:10.1007/s00464-014-3899-6

82. Böhm B, Rötting N, Schwenk W, Grebe S, Mansmann U. A prospective randomized trial on heart rate variability of the surgical team during laparoscopic and conventional sigmoid resection. *Arch Surg*. 2001;136(3):305-310. doi:10.1001/archsurg.136.3.305

83. Hogervorst MA, Brouwer A-M, van Erp JBF. Combining and comparing EEG, peripheral physiology and eye-related measures for the assessment of mental workload. *Front Neurosci*. 2014;8. doi:10.3389/fnins.2014.00322

84. Klingner J, Tversky B, Hanrahan P. Effects of visual and verbal presentation on cognitive load in vigilance, memory, and arithmetic tasks. *Psychophysiology*. 2011;48(3):323-332. doi:10.1111/j.1469-8986.2010.01069.x

85. Poock GK. Information processing vs pupil diameter. *Percept Mot Skills*. 1973;37(3):1000-1002. doi:10.1177/003151257303700363

86. Unsworth N, Robison MK. Tracking working memory maintenance with pupillometry. *Attention, Perception, Psychophys*. 2018;80(2):461-484. doi:10.3758/s13414-017-1455-x

87. Joshi S, Li Y, Kalwani RM, Gold JI. Relationships between pupil diameter and neuronal activity in the locus coeruleus, colliculi, and cingulate cortex. *Neuron*. 2016;89(1):221-234. doi:10.1016/j.neuron.2015.11.028

88. Mather M, Harley CW. The locus coeruleus: Essential for maintaining cognitive function and the aging brain. *Trends Cogn Sci*. 2016;20(3):214-226. doi:10.1016/j.tics.2016.01.001

89. Jiang X, Zheng B, Tien G, Atkins MS. Pupil response to precision in surgical task execution. *Stud Health Technol Inform*. 2013;184:210-214. doi:23400158

90. Brunyé TT, Eddy MD, Mercan E, Allison KH, Weaver DL, Elmore JG. Pupil diameter changes reflect difficulty and diagnostic accuracy during medical image interpretation. *BMC Med Inform Decis Mak*. 2016;16(1):77. doi:10.1186/s12911-016-0322-3

91. Mosaly PR, Mazur LM, Jones EL, et al. Quantifying the impact of cross coverage on physician's workload and performance in radiation oncology. *Pract Radiat Oncol*. 2013;3(4):e179-e186. doi:10.1016/J.PRRO.2013.02.007

92. Zheng B, Jiang X, Atkins MS. Detection of changes in surgical difficulty. *Surg Innov*. 2015;22(6):629-635. doi:10.1177/1553350615573582

93. Unsworth N, Robison MK. Tracking working memory maintenance with pupillometry. *Attention, Perception, Psychophys*. 2018. doi:10.3758/s13414-017-1455-x

94. Van Gerven PWM, Paas F, Van Merrienboer JJG, Schmidt HG. Memory load and the cognitive pupillary response in aging. *Psychophysiology*. 2004;41(2):167-174. doi:10.1111/j.1469-8986.2003.00148.x

95. Ahern S, Beatty J. Pupillary responses during information processing vary with Scholastic Aptitude Test scores. *Science*. 1979;205(4412):1289-1292. doi:10.1126/science.472746

96. Reilly JL, Lencer R, Bishop JR, Keedy S, Sweeney JA. Pharmacological treatment effects on eye movement control. *Brain Cogn*. 2008;68(3):415-435. doi:10.1016/j.bandc.2008.08.026

97. Shi Y, Ruiz N, Taib R, Choi E, Chen F. Galvanic skin response (GSR) as an index of cognitive load. In: *CHI '07 Extended Abstracts on Human Factors in Computing Systems - CHI '07*. New York, New York, USA: ACM Press; 2007:2651. doi:10.1145/1240866.1241057

98. Phitayakorn R, Minehart RD, Pian-Smith MCM, Hemingway MW, Petrusa ER. Practicality of using galvanic skin response to measure intraoperative physiologic autonomic activation in operating room team members. *Surgery*. 2015;158(5):1415-1420.

doi:10.1016/j.surg.2015.04.009
99. Berguer R, Smith WD, Chung YH. Performing laparoscopic surgery is significantly more stressful for the surgeon than open surgery. *Surg Endosc*. 2001;15(10):1204-1207. doi:10.1007/s004640080030
100. Haapalainen E, Kim S, Forlizzi JF, Dey AK. Psycho-physiological measures for assessing cognitive load. In: *Proceedings of the 12th ACM International Conference on Ubiquitous Computing - Ubicomp '10*. ; 2010:301. doi:10.1145/1864349.1864395
101. Gopher D, Braune R. On the psychophysics of workload - Why bother with subjective measures? *Hum Factors*. 1984;26(5):519-532. doi:10.1177/001872088402600504
102. Cooper GE, Harper RP. *The Use of Pilot Rating in the Evaluation of Aircraft Handling Qualities*. Washington, DC; 1969.
103. Vidulich MA, Tsang PS. Absolute magnitude estimation and relative judgement approaches to subjective workload assessment. *Proc Hum Factors Soc Annu Meet*. 1987;31(9):1057-1061. doi:10.1177/154193128703100930
104. Reid GB, Nygren TE. The subjective workload assessment technique: A scaling procedure for measuring mental workload. *Adv Psychol*. 1988;52(C):185-218. doi:10.1016/S0166-4115(08)62387-0
105. Hart SG. Nasa-Task Load Index (NASA-TLX); 20 years later. *Proc Hum Factors Ergon Soc Annu Meet*. 2006;50(9):904-908. doi:10.1177/154193120605000909
106. Sawyer A, Ayers S, Bertullies S, et al. Providing immediate neonatal care and resuscitation at birth beside the mother: parents' views, a qualitative study. *BMJ Open*. 2015;5(9):e008495. doi:10.1136/bmjopen-2015-008495
107. Harvey ME, Pattison HM. Being there: a qualitative interview study with fathers present during the resuscitation of their baby at delivery. *Arch Dis Child Fetal Neonatal Ed*. 2012;97(6):F439-43. doi:10.1136/archdischild-2011-301482
108. Harvey ME, Pattison HM, Merryl D, Harvey E. The impact of a father's presence during newborn resuscitation: a qualitative interview study with healthcare professionals. *BMJ Open*. 2013;3:2547. doi:10.1136/bmjopen-2013
109. American Academy of Pediatrics, American Heart Association. *Textbook of Neonatal Resuscitation (NRP). 7th Ed.: American Academy of Pediatrics; 2016.* 7th ed. (Weiner GM, Zaichkin J, eds.).; 2016.
110. King AJ, Hochheiser H, Visweswaran S, Clermont G, Cooper GF. Eye-tracking for clinical decision support: A method to capture automatically what physicians are viewing in the EMR. *AMIA Jt Summits Transl Sci proceedings AMIA Jt Summits Transl Sci*. 2017;eCollectio:512-521.

111. Law BHY, Cheung PY, Van Os S, Fray C, Schmölzer GM. Effect of monitor positioning on visual attention and situation awareness during neonatal resuscitation: A randomised simulation study. *Arch Dis Child Fetal Neonatal Ed*. 2019;105(3):285-291. doi:10.1136/archdischild-2019-316992

112. White MR, Braund H, Howes D, et al. Getting inside the expert's head: An analysis of physician cognitive processes during trauma resuscitations. *Ann Emerg Med*. 2018;72(3):289-298. doi:10.1016/J.ANNEMERGMED.2018.03.005

113. Lewis CH. *Using the "Thinking Aloud" Method In Cognitive Interface Design*. Yorktown Heights, NY: IBM; 1982.

114. Ericsson KA, Simon HA. Verbal reports as data. *Psychol Rev*. 1980;87(3):215-251. doi:10.1037/0033-295X.87.3.215

115. Nielsen J, Clemmensen T, Yssing C. Getting access to what goes on in people's heads? - Reflections on the think-aloud technique. In: *ACM International Conference Proceeding Series*. Vol 31. ; 2002:101-110. doi:10.1145/572020.572033

116. Branch JL. Junior high students and Think Alouds: Generating information-seeking process data using concurrent verbal protocols. *Libr Inf Sci Res*. 2001;23(2):107-122. doi:10.1016/S0740-8188(01)00065-2

117. Fox MC, Ericsson KA, Best R. Do procedures for verbal reporting of thinking have to be reactive? A meta-analysis and recommendations for best reporting methods. *Psychol Bull*. 2011;137(2):316-344. doi:10.1037/a0021663

118. Leighton JP. *Think-Aloud Interview Procedures - Measuring Problem-Solving Response Processes*. New York, NY: Oxford Scholarship; 2017. doi:10.1093/acprof:oso/9780199372904.001.0001

119. Fidler EJ. The reliability and validity of concurrent, retrospective, and interpretive verbal reports: An experimental study. *Adv Psychol*. 1983;14(C):429-440. doi:10.1016/S0166-4115(08)62248-7

120. Harte JM, Koele P. Psychometric and methodological aspects of process tracing research. In: London: Routledge; 1997:21-34.

121. Ericsson A. *Protocol Analysis : Verbal Reports as Data /*. Rev. ed. Cambridge, Mass. : MIT Press,; 1993.

122. Büttner OB, Silberer G. Video-cued thought protocols 1 video-cued thought protocols-a method for tracing cognitive processes at the point of purchase. In: Lowrey T, ed. *Brick & Mortar Shopping in the 21st Century*. New York, New York, USA: Psychology Press; 2006.

123. Unsworth CA. Using a head-mounted video camera to study clinical reasoning. *Am J Occup*

*Ther*. 2001;55(5):582-588. doi:10.5014/ajot.55.5.582
124. Elbabour F, Alhadreti O, Mayhew P. Eye tracking in retrospective think-aloud usability testing: is there added value? *J Usability Stud*. 2017;12:95-110.
125. Gegenfurtner A, Seppänen M. Transfer of expertise: An eye tracking and think aloud study using dynamic medical visualizations. *Comput Educ*. 2013;63:393-403. doi:10.1016/j.compedu.2012.12.021
126. Pelaccia T, Tardif J, Triby E, Charlin B. A novel approach to study medical decision making in the clinical setting: The "Own-point-of-view" perspective. Kline JA, ed. *Acad Emerg Med*. 2017;24(7):785-795. doi:10.1111/acem.13209
127. Omodei M, McLennan J, Wearing A. How expertise is applied in real-world dynamic environments: head-mounted video and cued recall as methodology for studying routines of decision-making. In: Betsch T, Haberstroh S, eds. *The Routines of Decision Making*. Mahwah, N.J. : Erlbaum,; 2005:271-288.
128. Eger N, Ball LJ, Stevens R, Dodd J. Cueing retrospective verbal reports in usability testing through eye-movement replay. In: BCS Learning & Development; 2007. doi:10.14236/EWIC/HCI2007.13
129. Charters E. The use of think-aloud methods in qualitative research an introduction to think-aloud methods. *Brock Educ J*. 2003;12(2). doi:10.26522/brocked.v12i2.38
130. Seagull FJ, Xiao Y. Using eye-tracking video data to augment knowledge elicitation in cognitive task analysis. *Proc Hum Factors Ergon Soc Annu Meet*. 2001;45(4):400-403. doi:10.1177/154193120104500429
131. Leighton JP. Item difficulty and interviewer knowledge effects on the accuracy and consistency of examinee response processes in verbal reports. *Appl Meas Educ*. 2013;26(2):136-157. doi:10.1080/08957347.2013.765435
132. Clement J. *Analysis of Clinical Interviews: Foundations and Model Viability*.; 2000.
133. Braun V, Clarke V. Using thematic analysis in psychology. *Qual Res Psychol*. 2006;3(2):77-101. doi:10.1191/1478088706qp063oa
134. Mayan M. Rigor. In: *Essentials of Qualitative Inquiry*. Left Coast Press; 2009:100-113.
135. Lincoln, Yvonna S, Guba EG. *Naturalistic Inquiry*. Beverly Hills, CA: SAGE Publications; 1985.
136. Guba EG. Criteria for assessing the trustworthiness of naturalistic inquiries. *Educ Commun Technol*. 1981;29(2):75-91. doi:10.1007/BF02766777
137. O'Donnell CPF, Kamlin COF, Davis PG, Morley CJ. Ethical and legal aspects of video recording neonatal resuscitation. *Arch Dis Child Fetal Neonatal Ed*. 2008;93(2):F82-F84. doi:10.1136/adc.2007.118505

138. Den Boer MC, Houtlosser M, Anje Van Zanten H, Foglia EE, Engberts DP, Te Pas AB. Ethical dilemmas of recording and reviewing neonatal resuscitation. doi:10.1136/archdischild-2017-314191

139. Parsons SE, Carter EA, Waterhouse LJ, Sarcevic A, O'Connell KJ, Burd RS. Assessment of workload during pediatric trauma resuscitation. *J Trauma Acute Care Surg*. 2012;73(5):1267-1272. doi:10.1097/Ta.0b013e318265d15a

140. Tofil NM, Lin Y, Zhong J, et al. Workload of team leaders and team members during a simulated sepsis scenario. *Pediatr Crit Care Med*. 2017;18(9):e423-e427. doi:10.1097/PCC.0000000000001258

141. Mohammadi M, Mazloumi A, Kazemi Z, Zeraati H. Evaluation of mental workload among ICU ward's nurses. *Heal Promot Perspect*. 2016;5(4):280-287. doi:10.15171/hpp.2015.033

142. American College of Obstetricians and Gynecologists, American Academy of Pediatrics. *Neonatal Encephalopathy and Neurologic Outcome*. Second. Washington, DC: American College of Obstetricians and Gynecologists; 2014.

143. Moroney WF, Biers DW, Eggemeier FT. Some measurement and methodological considerations in the application of subjective workload measurement techniques. *Int J Aviat Psychol*. 1995;5(1):87-106. doi:10.1207/s15327108ijap0501_6

144. Hendy KC, Hamilton KM, Landry LN. Measuring subjective workload: When is one scale better than many? *Hum Factors*. 1993;35(4):579-601. doi:https://doi.org/10.1177/001872089303500401

145. Young M, Stanton N. Mental Workload. In: Stanton NA, Hedge A, Brookhuis K, et al., eds. *Handbook of Human Factors and Ergonomics Methods*. 1st ed. Boca Raton : CRC Press; 2004:39-1-39-9. doi:10.1201/9780203489925

146. Rubio S, Díaz E, Martín J, Puente JM. Evaluation of subjective mental workload: A comparison of SWAT, NASA-TLX, and workload profile methods. *Appl Psychol*. 2004;53(1):61-86. doi:10.1111/j.1464-0597.2004.00161.x

147. Hoonakker P, Carayon P, Gurses AP, et al. Measuring workload of ICU nurses with a questionnaire survey: the NASA Task Load Index (TLX). *IIE Trans Healthc Syst Eng*. 2011;1(2):131-143. doi:10.1080/19488300.2011.609524

148. Yuan-me, i Xiao, Zhi-ming, Wang, Mian-zhen, Wang, Ya-jia L. The appraisal of reliability and validity of subjective workload assessment technique and NASA-task load index. *Chinese J Ind Hyg Occup Dis*. 2005;23(3):178-181. doi:16124892

149. Rall M, Manser T, Guggenberger H, Gaba DM, Unertl K. Patient safety and errors in medicine: development, prevention and analyses of incidents. *Anasthesiol Intensivmed Notfallmed*

*Schmerzther*. 2001;36(6):321-330. doi:10.1055/s-2001-14806

150. Croskerry P. Context is everything or how could I have been that stupid? *Healthc Q*. 2009;12. doi:10.12927/hcq.2009.20945

151. Gruppen LD, Frohna AZ. Clinical Reasoning. In: *International Handbook of Research in Medical Education*. Springer Netherlands; 2002:205-230. doi:10.1007/978-94-010-0462-6_8

152. Pelaccia T, Tardif J, Triby E, et al. From context comes expertise: How do expert emergency physicians use their know-who to make decisions? *Ann Emerg Med*. 2016;67(6):747-751. doi:10.1016/j.annemergmed.2015.07.023

153. Iedema R, Merrick ET, Rajbhandari D, Gardo A, Stirling A, Herkes R. Viewing the taken-for-granted from under a different aspect: A video-based method in pursuit of patient safety. *Int J Mult Res Approaches*. 2009;3(3):290-301. doi:10.5172/mra.3.3.290

154. Risko EF, Kingstone A. Eyes wide shut: Implied social presence, eye tracking and attention. *Attention, Perception, Psychophys*. 2011;73(2):291-296. doi:10.3758/s13414-010-0042-1

155. Eccles DW, Arsal G. The think aloud method: what is it and how do I use it? *Qual Res Sport Exerc Heal*. 2017;9(4):514-531. doi:10.1080/2159676X.2017.1331501

156. Human Performance Research Group NASA Ames Research Group. *NASA TLX Paper and Pencil Version Instruction Manual*. Moffett Feild, California; 1988.

157. Endsley MR. Toward a theory of situation awareness in dynamic systems. *Hum Factors J Hum Factors Ergon Soc*. 1995;37(1):32-64. doi:10.1518/001872095779049543

158. Jones RET, Connors ES, Endsley MR. A framework for representing agent and human situation awareness. In: *2011 IEEE International Multi-Disciplinary Conference on Cognitive Methods in Situation Awareness and Decision Support, CogSIMA 2011*. ; 2011:226-233. doi:10.1109/COGSIMA.2011.5753450

159. Poulton DA, Schmölzer GM, Morley CJ, Davis PG. Assessment of chest rise during mask ventilation of preterm infants in the delivery room. *Resuscitation*. 2011;82(2):175-179. doi:10.1016/j.resuscitation.2010.10.012

160. Schmölzer GM, Kamlin OCOF, O'Donnell CPF, Dawson JA, Morley CJ, Davis PG. Assessment of tidal volume and gas leak during mask ventilation of preterm infants in the delivery room. *Arch Dis Child Fetal Neonatal Ed*. 2010;95(6):F393-7. doi:10.1136/adc.2009.174003

161. Manley BJ, Dawson JA, Kamlin COF, Donath SM, Morley CJ, Davis PG. Clinical assessment of extremely premature infants in the delivery room is a poor predictor of survival. *Pediatrics*. 2010;125(3). doi:10.1542/peds.2009-1307

162. Endsley M, Jones D. SA Demons; The Enemies of Situation Awareness. In: *Designing for Situation Awareness*. CRC Press; 2011:31-42. doi:10.1201/b11371-5

163. Moshiro R, Ersdal HL, Mdoe P, Kidanto HL, Mbekenga C. Factors affecting effective ventilation during newborn resuscitation: a qualitative study among midwives in rural Tanzania. *Glob Health Action*. 1423;11(1). doi:10.1080/16549716.2018.1423862

164. McHale S, Thomas M, Hayden E, Bergin K, McCallion N, Molloy EJ. Variation in inspiratory time and tidal volume with T-piece neonatal resuscitator: Association with operator experience and distraction. *Resuscitation*. 2008;79(2):230-233. doi:10.1016/j.resuscitation.2008.06.024

165. Schmölzer GM, Kamlin OCOF, Dawson JA, Te Pas AB, Morley CJ, Davis PG. Respiratory monitoring of neonatal resuscitation. *Arch Dis Child Fetal Neonatal Ed*. 2010;95(4):295-303. doi:10.1136/adc.2009.165878

166. Salih ZNI, Draucker CB. Facilitators of and barriers to successful teamwork during resuscitations in a neonatal intensive care unit. *J Perinatol*. 2019;39(7):974-982. doi:10.1038/s41372-019-0380-3

167. Katakam LI, Trickey AW, Thomas EJ. Speaking up and sharing information improves trainee neonatal resuscitations. *J Patient Saf*. 2012;8(4):202-209. doi:10.1097/PTS.0b013e3182699b4f

168. Mesmer-Magnus JR, DeChurch LA. Information sharing and team performance: a meta-analysis. *J Appl Psychol*. 2009;94(2):535-546. doi:10.1037/a0013773

169. Pian-Smith MCM, Simon R, Minehart RD, et al. Teaching residents the two-challenge rule: A simulation-based approach to improve education and patient safety. *Simul Healthc*. 2009;4(2):84-91. doi:10.1097/SIH.0b013e31818cffd3

170. Clarke JR, Johnston J, Blanco M, Martindell DP. Wrong-site surgery: Can we prevent it? *Adv Surg*. 2008;42(C):13-31. doi:10.1016/j.yasu.2008.03.004

171. Okuyama A, Wagner C, Bijnen B. Speaking up for patient safety by hospital-based health care professionals: A literature review. *BMC Health Serv Res*. 2014;14:61. doi:10.1186/1472-6963-14-61

172. Sutcliffe, KM, Lewton, E, Rosenthal M. Communication failures: an insidious contributor to medical mishaps. *J Assoc Am Med Coll*. 2005;79(2):186-194. doi:10.1097/00001888-200402000-00019

173. O'Donovan R, McAuliffe E. A systematic review exploring the content and outcomes of interventions to improve psychological safety, speaking up and voice behaviour. *BMC Health Serv Res*. 2020;20(1):101. doi:10.1186/s12913-020-4931-2

174. Edmondson A. Psychological safety and learning behavior in work teams. *Adm Sci Q*. 1999;44(2):350. doi:10.2307/2666999

175. Yamada NK, Yaeger KA, Halamek LP. Analysis and classification of errors made by teams during neonatal resuscitation. *Resuscitation*. 2015;96:109-113. doi:10.1016/j.resuscitation.2015.07.048

176. Mackenzie C, Xiao Y. Access to macroeconomic from video review . In: Carayon P, ed. *Handbook of Human Factors and Ergonomics in Health Care and Patient Safety*. 1st ed. CRC Press; 2006:529-530. doi:10.1201/9781482269505

177. Skåre C, Calisch TE, Sæter E, et al. Implementation and effectiveness of a video-based debriefing programme for neonatal resuscitation. *Acta Anaesthesiol Scand*. 2018;62(3):394-403. doi:10.1111/aas.13050

178. Campbell D, Finan E. Impact of video-debriefing following simulated neonatal resuscitation in inter-professional teams. *Paediatr Child Health*. 2014;19(6):e88-e88. doi:10.1093/pch/19.6.e35-149

179. Lowndes BR, Forsyth KL, Blocker RC, et al. NASA-TLX assessment of surgeon workload variation across specialties. *Ann Surg*. September 2018:1. doi:10.1097/SLA.0000000000003058

180. Gurses AP, Carayon P, Wall M. Impact of performance obstacles on intensive care nurses' workload, perceived quality and safety of care, and quality of working life. *Health Serv Res*. 2009;44(2p1):422-443. doi:10.1111/j.1475-6773.2008.00934.x

181. Tubbs-Cooley HL, Mara CA, Carle AC, Gurses AP. The NASA Task Load Index as a measure of overall workload among neonatal, paediatric and adult intensive care nurses. *Intensive Crit care Nurs*. 2018;46:64-69. doi:10.1016/j.iccn.2018.01.004

182. Grier RA. How high is high? A Meta-Analysis of NASA-TLX Global Workload scores. *Proc Hum Factors Ergon Soc Annu Meet*. 2015;59(1):1727-1731. doi:10.1177/1541931215591373

183. Geis GL, Pio B, Pendergrass TL, Moyer MR, Patterson MD. Simulation to assess the safety of new healthcare teams and new facilities. *Simul Healthc J Soc Simul Healthc*. 2011;6(3):125-133. doi:10.1097/SIH.0b013e31820dff30

184. Jones BL, Parker-Raley J, Maxson T, Brown C. Understanding health care professionals' views of family presence during pediatric resuscitation. *Am J Crit Care*. 2011;20(3):199-208. doi:10.4037/ajcc2011181

185. Pichler G, Baumgartner S, Biermayr M, et al. Cerebral regional tissue Oxygen Saturation to Guide Oxygen Delivery in preterm neonates during immediate transition after birth (COSGOD III): An investigator-initiated, randomized, multi-center, multi-national, clinical trial on additional cerebral tissue oxygen saturation monitoring combined with defined treatment guidelines versus standard monitoring and treatment as usual in premature infants during

immediate transition: Study protocol for a randomized controlled trial. *Trials*. 2019. doi:10.1186/s13063-019-3258-y

186. te Pas A. Monitoring Neonatal Resuscitation Trial (MONITOR). U.S. National Library of Medicine. https://clinicaltrials.gov/ct2/show/NCT03256578. Accessed July 15, 2019.

187. Henneman EA, Cunningham H, Fisher DL, et al. Eye tracking as a debriefing mechanism in the simulated setting improves patient safety practices. *Dimens Crit Care Nurs*. 2014;33(3):129-135. doi:10.1097/DCC.0000000000000041

188. Khan RSA, Tien G, Atkins MS, Zheng B, Panton ONM, Meneghetti AT. Analysis of eye gaze: Do novice surgeons look at the same location as expert surgeons during a laparoscopic operation? *Surg Endosc*. 2012;26(12):3536-3540. doi:10.1007/s00464-012-2400-7