Human Factors and Ergonomics in Neonatal Resuscitation

by

Brenda Hiu Yan Law

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Department of Pediatrics
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Abstract

Approximately 10% of infants will require resuscitation at birth. Resuscitations are performed by nurses, physicians, midwives, and other Health Care Providers (HCPs), and include tasks such as vital signs monitoring and mask ventilation. Rarely, more advanced skills such as endotracheal intubation and chest compressions are needed. Programs such as Neonatal Resuscitation Program (NRP) provides standardized education and algorithms for health care providers (HCPs), outlining the equipment required, the sequence of tasks, and the decision-making process. However, despite education, experience, and algorithms, neonatal resuscitation remains a stressful endeavour prone to human error. Human factors and ergonomics is the study of human-system interactions and may reveal non-technical contributions to human performance. In this thesis, the effect of human factors on the performance of neonatal resuscitation was examined in a number of observational and simulation studies.

First, a review of the literature supports the hypothesis that neonatal resuscitation is affected by physical ergonomics (physical forces, equipment, resuscitation room), cognitive ergonomics (perception, situation awareness, decision-making, training), and organization ergonomics (teamwork, communication). Neonatal resuscitation is further affected by societal, cultural, and legal factors.

Second, in a randomized crossover simulation study involving 30 health care providers, I demonstrated that ergonomic equipment organization improved time to completion of a neonatal resuscitation simulation via faster equipment acquisition speed (176±21.6s using an ergonomic equipment box vs. 192.6±20.2s using a standard equipment bag, $p<0.0001$).

Third, in a pilot observational study, we obtained six eye-tracking recordings in the delivery room, and demonstrated that mobile eye-tracking glasses can be used to examine the

visual attention of health care providers performing neonatal resuscitations. Analysis revealed that, during neonatal resuscitation, health care providers have frequent shifts in gaze (saccades, 0.5 per sec) and divided their visual attention between the infant (35%, IQR=8%) and vital signs monitors (33%, IQR=10%).

Fourth, in a randomized simulation study, we used an objective situation awareness measure (Situation Awareness Global Assessment Tool, SAGAT), eye-tracking, and a standardized resuscitation checklist to compare the performance of 30 health care providers when leading a neonatal resuscitation using one of two different vital signs monitor positions. We demonstrated that SAGAT could be adapted for use to evaluate human performance during neonatal resuscitation. However, we did not demonstrate any difference in visual attention, SAGAT scores, or checklist scores between the central or peripheral monitor positions.

Finally, in an observational study of 24 endotracheal intubations in the neonatal intensive care unit, we used eye-tracking glasses to capture the visual attention of intubators and to study verbal communication between team members. Visual attention during intubations differs from visual attention during neonatal resuscitation in the delivery room; during intubations, more visual attention was directed at the infant (median 50%, IQR 39-61%), but saccades were similar. Team communication of both verbal medication orders and vital signs revealed the use of non-standard and potentially ambiguous language.

Using observations in the clinical environment, mobile eye-tracking glasses, and high-fidelity simulation, we examined physical, cognitive, and organizational ergonomic factors during neonatal resuscitations. Better understanding of these non-technical factors might improve resuscitation of newborns, and ultimately improve neonatal outcomes.

Preface

This thesis consists of multiple research projects which have received research ethics approval from the University of Alberta Research Ethics Board, including: i) "Effect of Equipment Organization on Neonatal Resuscitation Under Simulation Conditions", Pro00065363, June 8, 2016; ii) "Sustained Inflations to achieve lung aeration at birth – a randomized control trial", Pro00034524, November 23, 2012; ii) "Effect of Monitor Placement on Situational Awareness and Visual Attention in Simulated Neonatal Resuscitations", Pro00071387, March 6, 2017; iii) "Analysis of Visual Attention and Team Communications during Neonatal Resuscitations in the Delivery Room Using Eye-Tracking: an Observational Study", Pro00077581, November 9, 2017.

Research conducted for the thesis was done in collaboration with our research team. A majority of the literature review that forms Chapter 2 is my original work. Chapter 3 has been published as Law BHY, Cheung PY, Wagner M, van Os S, Zheng B, Schmolzer G. Analysis of neonatal resuscitation using eye tracking: a pilot study. Arch Dis Child Fetal Neonatal Ed 2018 Jan;103(1):F82-F84. I was responsible for the data analysis and manuscript composition. Dr. Wagner provided expertise on eye-tracking and assistance with manuscript edits. Dr. Cheung contributed to manuscript edits. Dr. Schmölzer was the supervisory author and involved with concept formation, data collection and manuscript edits. Dr. Zheng assisted with data collection, provided expertise on eye-tracking, and assisted with manuscript edits.

Chapter 4 has been published as Law B, Cheung P, O'Reilly M, Fray C, Schmölzer G. Reorganizing Neonatal Resuscitation Equipment Improves Performance Speed Under Simulation Conditions. In: Duffy V, Lightner N, editors. Advances in Human Factors and Ergonomics in Healthcare and Medical Devices: Proceedings of the AHFE 2017 International Conferences on

Human Factors and Ergonomics in Healthcare and Medical Devices, July 17-21, 2017, The Westin Bonaventure Hotel, Los Angeles, California, USA Cham: Springer International Publishing; 2018. p. 343-351. I conceptualized the project and performed data collection, data analysis, and manuscript composition. Caroline Fray, Sylvia van Os, and Dr. O'Reilly assisted with data collection and manuscript edits. Dr. Cheung contributed to manuscript edits. Dr. Schmölzer was the supervisory author and assisted with conceptualizing the project and manuscript edits.

Chapter 5 has been submitted for review to the Archives of Diseases of Childhood, Fetal and Neonatal Edition. I conceptualized the project and performed data collection, data analysis, and manuscript composition. Caroline Fray and Sylvia van Os assisted with data collection and manuscript edits. Dr. Cheung contributed to manuscript edits. Dr. Schmölzer was the supervisory author and assisted with conceptualizing the project and manuscript edits.

Chapter 6 constitutes a significant portion of my original work. I conceptualized the project and performed data collection, data analysis, and manuscript composition. Caroline Fray and Sylvia van Os assisted with data collection. Emily Zender assisted with data analysis. Dr. Schmölzer was the supervisory author and assisted with conceptualizing the project and manuscript edits.

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Abbreviations

AOI	- Area of Interest
ETT	- Endotracheal Tube
HCP	- Healthcare Provider
HF/E	- Human Factors and Ergonomics
HR	- Heart rate
NICU	- Neonatal Intensive Care Unit
NR	- Neonatal Resuscitation
NRP	- Neonatal Resuscitation Program
SA	- Situation Awareness
SpO_2	- Oxygen Saturation
VA	- Visual Attention

Chapter 1. Introduction

1.1 Neonatal Resuscitation

Most newborn infants successfully make the transition from fetal to neonatal life unassisted. However, an estimated 10% of newborns need help to establish effective ventilation, and 1% need more extensive resuscitation such as endotracheal intubation, chest compressions, and medications.[1] This risk increases with factors such as maternal conditions (pre-eclampsia, gestatioan diabetes, etc), prematurity, congenital anomalies, and birth asphyxia.[1] Other than intrinsic patient factors, health care provider performance also has an impact on neonatal outcomes; the Joint Commission on Accreditation of Healthcare Organizations reported that failures in providing effective neonatal resuscitation account for more than two thirds of perinatal mortality and morbidity.[2] Indeed, the transition period remains the highest risk time in infancy; neonatal mortality under 7 days is 3 deaths per 1000 live births in Canada, as compared with 1 death per 1000 live births between 1 and 11 months of age.[3]

Health care providers who attend deliveries and care for high-risk infants in the Neonatal Intensive Care Unit (NICU) must be prepared to provide this assistance in a timely manner, in a likely stressful environment. To improve outcomes, programs such as the Neonatal Resuscitation Program (NRP®) provides standardized education and algorithms to guide health care providers in neonatal resuscitation.[4] While emphasis has previously been placed on education, other non-technical factors – human factors – have been increasingly recognized as contributors to HCP performance during neonatal resuscitation and is now designated as a research priority.[5]

1.2 Human factors and Ergonomics

Human factors and ergonomics (HF/E) is defined as the "scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to optimize human well-being and overall system performance."[6] As a field, it can inform the design and optimization of physical equipment, technologies, processes, team dynamics, training, and organization. Human factors and ergonomics can be divided into physical, cognitive, and organizational ergonomics. *Physical ergonomics* addresses optimization of physical work as it relates to human anatomy, biomechanics, and stresses. *Cognitive ergonomics* examines mental activity, thought processes, and how a human makes decision and interacts with elements of the system (e.g., perception, situation awareness, and decision-making processes). *Organization ergonomics* relates to broader psychosocial aspect of humans and how teams and processes work (e.g. teamwork, communication, health care organization and structure).[6,7]

Potentially, human factors and ergonomics principles can be applied to neonatal resuscitation to help improve our understanding of this critical task. Improved understanding of HF/E in the neonatal resuscitation and NICU environments may reveal opportunities to optimize human performance through changes in physical spaces, workflow, and training, with the goal of increasing neonatal resuscitation effectiveness and ultimately improving neonatal outcomes.

1.3 Technology and the Study of Human Factors and Ergonomics: Video-recording, Simulation, and Eye-Tracking

How can we study HF/E in neonatal resuscitation? While basic steps of neonatal resuscitation are frequently performed, higher-level resuscitation such as endotracheal intubations, chest compressions, and medications occur rarely and unpredictably. Simulation, frequently used an educational tool, can be used from a research perspective to overcome this limitation.[8] Using simulation, researchers can replicate these high acuity low occurrence (HALO) events to study human performance during complex neonatal resuscitation. Simulation also allows researchers to intervene in the scenario without affecting patient care; for example, scenarios can be paused to ask questions of participants. Researchers can also intentionally disrupt the simulation environment (e.g. cause deterioration in the simulated patient, introduce distractions) to study health care provider responses to adverse conditions. Simulations have been successfully used to study various aspects of neonatal resuscitation.[9-13]

Simulation can be performed with basic technology; however, technologies such as high-fidelity mannequins may increase our ability to realistically replicate resuscitation events, including factors that could affect human performance. For example, a mannequin that replicates pulses and chest movement engages participants' tactile and visual senses, and may more accurately replicate the time needed for clinical assessment and decision-making. However, there are limitations to simulation technology; for example, neonatal mannequins may not consistently replicate the neonatal airway.[14,15]

Video recording has been used to study health care provider performance during neonatal resuscitation.[16,17] Mobile eye-tracking technology further augments the data that could be collected in an audio-visual recording. Eye-tracking glasses use reflected infrared light to track pupillary movement and imaging processing to incorporate gaze patterns as markers into video from a participant's viewpoint[18,19]; in short, it allows researchers to "see" what an individual was looking at, or their visual attention. Health care providers can wear mobile eye-tracking glasses to record their visual attention during clinical tasks such as neonatal resuscitation or endotracheal intubation. This information may offer insight into an individual's cognition separate from their physical actions.

Using a combination of simulation, eye-tracking, and clinical observational studies, I aimed to examine aspects of human factors and ergonomics as it pertains to neonatal resuscitation.

1.4 Thesis Overview

The studies presented in this thesis examined aspects of physical, cognitive, and organization ergonomics in neonatal resuscitation in the delivery room and in the Neonatal Intensive Care Unit (NICU). They consist of a literature review, two observational studies of health care providers using mobile eye-tracking glasses (Chapters 3 and 5), and two simulation studies (Chapters 4 and 6).

In Chapter 2, Human factors and ergonomics is described in general. The model of systems analysis as presented by Moray[20] is used to conceptualize the multidimensional aspects of HF/E as it applies to neonatal resuscitation. Studies that highlight the existing understanding of human factors and ergonomics with regards to neonatal resuscitation are presented.

Chapter 3 describes a simulation study of one aspect of physical ergonomics – equipment organization – as it relates to neonatal resuscitation. An ergonomic neonatal resuscitation equipment box was developed and tested using a cross-over simulation study design, in which health care providers acted as an assistor in two simulated neonatal resuscitation, using either the ergonomic equipment box or an equipment bag standard to this institution. Equipment acquisition time, overall scenario completion time and participant satisfaction was measured.

Chapter 4 describes a pilot observational study in the delivery room. Health care providers standing at the head of the resuscitation warmer wore mobile eye-tracking glasses to record their visual attention during neonatal resuscitations to test if this technology could be used to quantify visual attention (both visual attention distribution and saccade behavior) in this clinical environment.

Chapter 5 describes a randomized simulation study comparing visual attention and situation awareness when health care providers resuscitated a newborn with either a peripheral vital signs monitor position, or central (eye-level) vital signs monitor. I hypothesized that Situation Awareness Global Assessment Tool (SAGAT) could be used to quantify situation awareness in neonatal resuscitation, and that a simple ergonomic change would impact situation awareness (SAGAT score), visual attention (eye-tracking data), and overall performance (checklist score).

Finally, Chapter 6 describes a second observational study using mobile eye-tracking glasses, now in the NICU. In this study, health care providers wore eye-tracking glasses during non-urgent neonatal endotracheal intubations, a procedure critical to resuscitation of high-risk newborns such as extreme preterm infants. Video recordings were then analyzed to examine both intubator visual attention and team communication during this critical event.

Chapter 2. Human Factors and Ergonomics in Neonatal Resuscitation: A Review

Brenda H. Law MD[1,2], Georg M. Schmölzer, MD PhD[1,2]

[1]Centre for the Studies of Asphyxia and Resuscitation, Royal Alexandra Hospital, Edmonton, Canada

[2]Department of Pediatrics, University of Alberta, Edmonton, Canada

2.1 Abstract

Importance: Effective neonatal resuscitation is important for reducing neonatal mortality and morbidity in high and low resource settings. Non-technical factors can lead to an increase in human errors during neonatal resuscitation.

Observations: Human factors and ergonomics can be divided into physical, cognitive, and organizational factors; all categories are relevant to neonatal resuscitation. Existing studies on physical ergonomics in neonatal resuscitation include usability of bag-mask devices, physical forces used to perform chest compressions, and equipment and resuscitation room organization. Cognitive ergonomics examined in neonatal resuscitation include accuracy of clinician perception of clinical parameters (e.g., heart rate, chest rise), decision-making, situation awareness, and training effectiveness. Organizational ergonomics in neonatal resuscitation have focused on teamwork and team training. Finally, larger societal, cultural and legal factors also influence the practice of neonatal resuscitation.

Conclusions and Relevance: Human factors and ergonomics affects all aspects of neonatal resuscitation including physical, cognitive, and organizational factors. Study of human factors in neonatal resuscitation focuses mainly on teamwork and communication, simulation training, and vital sign monitoring. Human factors and ergonomics principles can be applied to improve patient safety and quality of care during neonatal resuscitation.

2.2 Introduction

To provide effective neonatal resuscitation in the delivery room, health care providers (HCPs) must combine cognitive, psychomotor, and communication skills to analyze data, make decisions, and coordinate timely interventions, all under intense time pressure. This stressful situation can result in decreased human performance, increasing the risk for medical errors. Therefore, educational programs such as the Neonatal Resuscitation Program (NRP)[4] have been developed to decrease errors and improve skills of HCPs during neonatal resuscitation. Although dissemination of these educational programs has contributed to improved HCPs skills and decreased neonatal mortality, errors during neonatal resuscitation remain common. Several studies reviewed audiovisual recordings of neonatal resuscitations and reported error rates by HCPs between 16–55%.[17,21,22] Most noticeably, deficiencies in *non-technical* skills (e.g., working memory, decision making, or teamwork) rather than technical skills were the reasons for most fatal errors and poor patient outcomes.[23]

In comparison, since the 1960's, the rate of commercial aviation accidents (currently >4 accidents per 1 million departures in the US) has steadily declined despite increasing aviation usage.[24] However, human error remains a major contributing factor in aviation accidents; 70-80% of aviation accidents involve some aspects of human error. Studies of human factors and ergonomics (HF/E) of aviation incidents reported that workload, fatigue, machine-human interfaces, cockpit teamwork, and communication contributed to these errors. In addition, the cultural shift away from *individual blame* towards *analysis of the entire system* allows continuous improvement of aviation safety.[24]

Application of HF/E principles and systems analysis have been successfully translated to health care, including in anaesthesia, surgery, and intensive care. Cooper et al.[25] used interviews and critical incident analysis to examine how HF/E including fatigue, workload, or labeling contributed to adverse events during anaesthesia. Their results led to a system change and introduction of checklists and patient safety checks.[26] Similarly, HF/E principles are used to optimize teamwork and communication in emergency rooms and intensive care units. Many of the same principles also apply to the stressful environment during neonatal resuscitation in the delivery room.

Knowledge about the effects of HF/E on HCP performance and their influence on successful neonatal resuscitation has been identified as a research priority by the International Liaison Committee on Resuscitation.[5] HF/E and systems analysis could be used to analyze the performance of a neonatal resuscitation system to maximize HCP function and mitigate errors. This article aims to describe the current knowledge of HF/E in neonatal resuscitation and how these factors can be applied to improve outcomes for newborn infants.

2.3. Human Factors and Ergonomics

The interactions between human participants (i.e., HCP, patients, and their families) and the medical system (i.e., physical spaces, treatments, processes, and organizations) are complex. HF/E examines these human-system interactions, informing the design and optimization of physical equipment, technologies, processes, team dynamics, training, and organization.

HF/E is defined as the "scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to optimize human well-being and overall system performance."[6] Incorrectly, HF/E is often interchangeably used with patient safety and quality improvement. However, HF/E principles could be used to understand the cognitive processes to provide insight into the root cause of errors. HF/E can also aid in the implementation, dissemination, and acceptance of practice changes. Finally, HF/E principles can be applied to the design of equipment, physical spaces, and processes to optimize human performance, improve efficiency, decrease worker injuries, improve HCP satisfaction, and decreased costs.[7,27]

HF/E can be divided into three main domains: 1) physical ergonomics, 2) cognitive ergonomics, and 3) organizational ergonomics (Table 2.1). *Physical ergonomics* addresses optimization of physical work as it relates to human anatomy, biomechanics, and stresses.[6] *Cognitive ergonomics* examines mental activity, thought processes, and how a human makes decision and interacts with elements of the system (e.g., study of protocols, decision-making processes, and information loading). *Organization ergonomics* relates to broader psychosocial aspect of humans and how teams and processes work, and include teamwork, communication, workflow, health care organization, and structure.

Applying systems analysis is an alternate method of conceptualizing these domains of HF/E.[20] In a health system, physical space and equipment, individual performance, interpersonal behaviors, organization considerations, as well as societal and legal factors all influence overall system function. These factors represent layers of complexity, evolving ever outwards, interconnected, and interdependent (Figure 2.1). For example, the simple task of bag-mask ventilation is dependent on the reliability and usability of the bag-mask device, an individual's perception of adequate ventilation in their assessment of the infant, coordination of the team's activities through shared mental model and communication, all occurring within the culture of the healthcare organization and the wider societal values regarding neonatal resuscitation. Challenges in each of these areas can result in ineffective neonatal resuscitation, resulting in increased neonatal mortality and morbidity.

2.4 Physical Ergonomics: Human Limitations, Equipment Design, and the Resuscitation Room

Physical ergonomics describes the interactions between equipment, work environment, and human physical attributes in the performance of physical tasks. During neonatal resuscitation, these tasks include basic tasks (e.g., acquisition and preparation of equipment or placement of a pulse oximeter probe) and higher order tasks (e.g., bag-mask ventilation or chest compressions). The performance of these tasks is limited by human physical limitations (e.g., fatigue), design of resuscitation equipment, organization of this equipment, and design of the resuscitation space itself.

2.4.1 Chest compressions – An Example of Human Limitations

Despite being performed on patients of much smaller size, HCPs still become quickly fatigued while performing chest compressions, resulting in degradation of chest compression quality.[28] This phenomenon is demonstrated across different chest compression ratios[28] and techniques.[29]

2.4.2 Equipment Design, Organization, and the Resuscitation Room

While mask ventilation is frequently performed in neonatal resuscitation, the effectiveness of mask ventilation depends on the patient, equipment, and HCP performance. Although many studies have examined the performance (e.g., tidal volume delivery and mask leak) of different ventilation devices (e.g., self-inflating bags, flow-inflating bags, and T-Piece resuscitators)[30,31], studies examining physical ergonomics from the HCP perspective are limited and mostly relied on limited evaluations such as subjective evaluations of comfort and subjective usability (e.g., ease of use, comfort, and perception of fatigue), usability testing by assembly and disassembly of the test equipment, and anthropometric data (hand size).[32-34] These evaluations might not correlate with objective performance measures. Furthermore, training, experience, and familiarity with each ventilation device plays a crucial role in the effectiveness of mask ventilation.[34-36]

The organization of neonatal resuscitation equipment can further influence performance.[37] In a simulation study, the multitude of equipment required for an emergency UVC insertion has been postulated as resulting in prolonged time to insertion as compared to an intra-osseous.[12] Rooms dedicated to neonatal resuscitation have been proposed as one solution to physical ergonomic issues. Current standards for the design of a Neonatal Intensive Care Unit outline requirements for dedicated neonatal resuscitation rooms.[38] Separate resuscitation rooms may improve timely access to advanced resuscitation equipment. Furthermore, dedicated neonatal resuscitation rooms, in conjunction with other process changes, resulted in improved stabilization times[39] and less hypothermia.[40] However, studies focusing on the physical ergonomics of resuscitation room design and their impact on HCPs performance and workflow are lacking. In comparison, ergonomics studies of trauma stabilization rooms have reported benefits in physical ergonomics and teamwork.[41]

2.5 Cognitive Ergonomics: Perception, Situation Awareness, Decision Making, and Training

Along with optimal performance of technical skills, the cognitive processes by which HCPs decide whether an infant requires resuscitation, what interventions should be performed, and whether this resuscitation has been effective are equally important for a successful resuscitation. Human cognition is a complex process that involves perception, attention, situation awareness (SA), working and long-term memory, knowledge, and decision-making.[42] Even expert HCPs are limited by their human perception and their attentional and memory resources.

2.5.1 Perception

Accurate clinical assessment is essential for decision-making during neonatal resuscitations. However, several studies reported that the human perception of clinical assessment (e.g., heart rate, chest rise, or mask leak) is imprecise.[43-45] Therefore, relying on human perception alone might result in increased rates of errors and poorer outcomes. To overcome these inaccuracies, technology has been introduced to assess clinical parameters during neonatal resuscitation. Electrocardiograms assess heart rate faster and more accurately compared to auscultation (mean difference of 14 beats/min) or palpation (mean difference of 22 beats/min), respectively.[43] Similarly, respiratory function monitors can objectively assess effective ventilation compared to clinical observations of chest rise.[46] However, the added technology and additional data increases the complexity of the resuscitation environment (Figure 2.2), and might cause HCPs to divide their visual and mental attentions away from the infant. This is supported by a pilot study using eye-tracking glasses, which reported that 33% of visual attention of HCPs during neonatal resuscitation was directed towards monitors, timers, and pressure gauges.[47] However, averting visual attention away from the infant does not affect performance during mask ventilation.[48] A solution to divided visual attention might be to utilize an alternative sensory modality (e.g., sound) to represent visual signs changes.[49]

2.5.2 Situational Awareness

Accurate perception of an infant's condition is only one aspect of a HCPs assessment of the overall resuscitation event. SA is defined as "*the perception of the elements in the environment and the comprehension of their meaning and the projection of their status into the future.*"[50] This construct guides our understanding of how perception, attention, and knowledge leads to understanding, anticipation, and decision-making. However, evidence about SA of HCPs during neonatal resuscitation is limited to subjective assessment tools, which measure the impact of a training regimen on HCP performance during neonatal resuscitation.[51] More importantly, assessment of SA using objective assessment tools during neonatal resuscitation is lacking.

In addition, negative factors (or *"demons*") can inhibit SA (Table 2.2).[52] WAFOS (Workload*,* Anxiety, Fatigue, and Other Stressors) represents a group of SA demons particularly relevant to neonatal resuscitations, which are often stressful, unanticipated, and anxiety-provoking events, often occurring outside of regular working hours. A qualitative study of midwives in Tanzania reported that anxiety and fear due to stress of ventilating a non-breathing baby was identified as a contributing factor for poor performance.[53]

2.5.3 Algorithms, Cognitive Aids, and Training

Educational programs (e.g, NRP (North America),[4] Newborn Life Support (Europe)[54]) have been developed to standardize education, create a shared mental model, and streamline decision-making. These educational programs use algorithms detailed in flowcharts to help HCPs make decisions during neonatal resuscitation. These flowcharts reduce the dependence on HCPs' long-term memory for items such as oxygen saturation targets. However, McLanders et al.[55] reported that the algorithms used scored poorly in HF design principles; in particular, these algorithms are not designed for easy accessibility or readability during medical emergencies. Furthermore, no study has reported that the presence of a flowchart alone improves performance in novice HCPs.[55] Future cognitive aids (tablet application or paper-based aids) might improve usability[56,57]; however, these cognitive aids must take HF design principles into account.

Despite the numerous cognitive factors affecting individual HCP performance, most studies focused on what impact training has in the performance of neonatal resuscitation. While knowledge and skill acquisition remains an important aspect of individual performance, training alone might not improve performance or neonatal outcomes. A Cochrane review identified 14 randomized trials examining the effect of standardized formal neonatal resuscitation training (SFNRT) on knowledge, skills, and behaviours, and neonatal outcomes.[58] Although several studies demonstrated improvements in skills and knowledge retention, only a few studies demonstrated improvements in outcomes; three randomized trials reported a decrease in neonatal mortality in developing countries (Relative Risk 0.88, 95% Confidence Interval 0.78 to 1.00).[58]

While each factor plays a role in individual performance, an improved understanding about the interactions of perception, SA, knowledge, skills, and decision-making might lead to improvements in algorithm design, cognitive aids, or training and ultimately to improve outcomes for newborn infants.

2.6 Organizational Ergonomics: Teamwork, Communication, and Organization Culture

Beyond individual performance, HCPs must work as a team to be effective. However, team composition depends on availability, level of care, and institutional standards. More importantly, lack of skilled HCPs is a potential limitation for successful resuscitation.[59-61] However, there is conflicting evidence that the presence of an attending neonatologist improves outcomes of infants with low Apgar scores.[59-61] Therefore, centers have successfully implemented specialized neonatal resuscitation teams, which consist of HCPs with various levels of competence and learners (e.g., medical students, residents, and nursing students).[62]

2.6.1 Teamwork

Having the right team members at the right place at the right time might not be enough to ensure effective teamwork. Team dynamics, the psychological forces that influence interactions among individuals in a group, affect overall team function and may hinder a team's ability to achieve its goal.[63] Important aspects of teamwork and the ability of a team to be effective depends on psychological factors and stressors (Table 2.3). These factors can be mitigated through team training and process changes, which have been shown to correlate with improved patient outcomes, decreased HCP burnout, and increased HCP satisfaction.[64]

Clary-Muronda et al.[65] reviewed 10 instruments to measure teamwork performance in neonatal resuscitation. The TEAM (Team Emergency Assessment Measure)[66] and the checklist developed by Lockyer et al.[67] have been assessed during simulated neonatal resuscitations. To examine team behaviours, Thomas et al.[21] reviewed the frequency of teamwork behaviours of video-recorded neonatal resuscitations and reported a weak correlation of specific team behaviours with NRP compliance. Adapted from aviation, these teamwork behaviours included: Information sharing, Inquiry, Assertion, Intentions Shared, Teaching, Evaluation of plans, Workload management, Vigilance / Environmental awareness, Overall Teamwork, and Leadership.[69] In a review of a subset of these resuscitations requiring more complex interventions, a specific team behaviour – vigilance – was correlated with fewer errors.[21]

To improve these non-technical, team-based skills and team dynamics, an increase in team-based training for neonatal resuscitation has been proposed. Several studies reported that simulation-based training (SBT) improves neonatal resuscitation teamwork.[70] In particular, Crisis Resource Management (CRM), Anesthesia Non-Technical Skills (ANTS), or TeamSTEPPS (Team Strategies and Tools to enhance Performance and Patient Safety) might be reasonable approaches to improve neonatal resuscitation teamwork.[63,71,72] CRM was originally developed by the National Aeronautics and Space Administration in response to aviation accidents caused by ineffective crew communication and teamwork.[73] Rovarmo et al.[66]

compared a CRM and ANTS training session prior to a simulated resuscitation vs. no team training and reported that neither team training improves teamwork.

TeamSTEPPS is a training framework to improve teamwork behaviours and communication in HCPs. Sawyer et al.[74] reported significant improvements in all aspects of the TeamSTEPPS model (i.e., team structure, leadership, situation monitoring, mutual support, and communication) in simulated neonatal resuscitations after TeamSTEPPS training. Furthermore, there was an increased rate of error detection observed during simulated resuscitation following TeamSTEPPS training; nurses challenged an incorrect epinephrine dose twice as frequently after training (38% vs 77%, p=0.063). These results are supported by a randomized controlled trial comparing low fidelity NRP skills training with low fidelity training and team training or high-fidelity training and team training.[75] The trial reported that team training resulted in increased frequency of teamwork behaviors (12.8 vs 9 behaviors per minute; p=0.001) and 24% faster time to scenario completion. While these results are promising, further studies are needed to determine what teamwork training will improve non-technical skills and neonatal outcomes during real-life resuscitations.

2.6.2 Communication

Effective communication is an important aspect of teamwork and communication during neonatal resuscitation. Yamada et al.[13] examined the impact of standardized communication techniques on resuscitation errors and reported that standardized communication resulted in a trend towards decreased error rate and improved time to interventions during simulated neonatal resuscitations.[13] Simple tools such as checklists have also been proposed to facilitate teamwork by improved role clarity, information sharing, and encouragement of open communications.[76]

Combining Checklists and CRM training can also improve communication among obstetric and neonatal practitioners.[77]

2.6.3 Organization Culture

The medical and organization culture has been identified as a barrier to effect teamwork in neonatal resuscitation.[2] In particular, an organization's safety culture, defined as "the product of individual and group values, attitudes, perceptions, competencies, and patterns of behavior that determine the commitment to, and the style and proficiency of, an organization's health and safety management",[78] may facilitate or hinder the performance of resuscitation teams. A recent survey of 44 NICUs reported considerable variation in safety culture, with measures of safety climate and teamwork correlating with lower rates of healthcare-related infections.[79] The effect of targeted team training using CRM or TeamSTEPPS on overall organization culture is unclear, and the presence or absence of safety culture has yet to be assessed during neonatal resuscitation. Studies are needed to examine in interactions between team training, safety culture, and effectiveness of neonatal resuscitation.

2.7 Neonatal Resuscitation and Society: Economic, Legal, and Cultural Context

Neonatal resuscitation exists in a greater societal context, and is directly impacted by legal, cultural, and economic realities. Physical, cognitive, and organization ergonomics are affected by these systemic factors. Therefore, studies examining HF/E principles during neonatal resuscitation should also address these factors. Most studies examining neonatal transition and resuscitation occurred in high-resource countries, however neonatal mortality in low and middle-income countries accounts for the majority of the global neonatal mortality.[80] Different HF/E challenges exist for neonatal resuscitation in lower resource countries; equipment such as bag-mask devices that require oxygen supply might be ill-suited for environments where gas supplies are unavailable.

In a mixed-methods study of provider perspectives towards neonatal resuscitation, 36% cited legal and societal reasons to justify comfort care in periviable infants.[81] Legal requirements differ between different jurisdictions on mandated resuscitation post birth. Laws such as the Born-Alive Infants Protection Act in the United States, while not strictly enforced, are perceived to have a potential impact on resuscitation practices for extreme preterm infants.[82]

Cultural differences and beliefs also influence non-technical aspects of neonatal resuscitation. Healthcare providers consider the resuscitation of neonates, particularly at the limit of viability, differently than the resuscitation of older children and adults. Studies have demonstrated that physicians are less likely to consider intensive resuscitation in extreme preterm infants compared to older children or adults with similar estimated risk of mortality and morbidity.[83] There are differences in decision-making between countries in a similar economic and geographical area, which suggests an influence of a greater societal culture on attitudes surrounding neonatal resuscitation.[84] Similarly, a recent qualitative study of HCPs in India identified cultural differences such as gender bias, an acceptance of neonatal mortality, and a rigid medical hierarchy as barriers to improving neonatal resuscitation.[85] Cultural differences in communication and medical hierarchy may necessitate the adaptation of team training frameworks such as CRM and TeamSTEPPS, which were developed in a North American context.

2.8 Gaps in Knowledge and Current Limitations

Many aspects of physical, cognitive, and organizational ergonomics in neonatal resuscitation have been studied; however, significant knowledge gaps exist, which are opportunities for future research. Most studies are small, inadequately powered, and focused on only one aspect of HF/E and may not consider the interactions between the different HF/E domains. Designing adequate studies with controls, ensuring blinding, and validating neonatal resuscitation-specific performance measures pose further challenges. Furthermore, outcomes are often mostly on short-term, HCP effects (e.g., increase in knowledge, simulation performance) rather than on long-term improvements or clinical outcomes. Future studies addressing these concerns might improve acceptance of HF/E concepts in neonatal resuscitation and increase the use of human factors-based interventions in improving patient safety and quality.

2.9 Technology and Human Factors in Neonatal Resuscitation: Not a Silver Bullet

Technology could be helpful in studying and improving HF/E in neonatal resuscitation. Introduction of monitoring devices to assess heart rate, oxygen saturation, or respiratory functions provides objective clinical assessment, which might overcome the limitations of human perception. Technologies such as mobile eye-tracking and wearable stress-response monitoring (e.g. heart rate, galvanic skin response) provide additional tools to understanding human performance in the clinical environment. Furthermore, realistic, high-fidelity simulators support the study and teaching of HF/E specific to neonatal resuscitation.

However, technology might also introduce new HF/E issues. Increased data points (e.g., respiratory functions monitor) might introduce additional attentional and cognitive demands on HCPs. Therefore specialized training might be required to maximize the benefit of these additional monitoring parameters. Prior to the widespread adoption of further monitoring, more research is needed to determine how to optimally present this information to HCPs. Integrating this information into decision support systems may be one way of maximizing the benefit of additional data while minimizing cognitive overload.

2.10 Summary

HF/E affects all aspects of neonatal resuscitation from the design and organization of resuscitation equipment and environments, to understanding individual HCP performance, to teamwork and team communication, all within a greater legal, societal, and cultural framework. Opportunities exist to further apply HF/E principles to improve patient safety and quality of care during neonatal resuscitation. Further research should address specifics of physical, cognitive, and organization ergonomics to improve patient outcomes during neonatal resuscitation.

Table 2.1 Domains in Human Factors and Ergonomics and Examples in Neonatal Resuscitation

Domain	Description	Examples in Neonatal Resuscitation
Physical Ergonomics	Study and optimization of physical work as it relates to human anatomy, biomechanics, stresses, and interactions with physical objects.	- Usability of bag-mask ventilation devices - Physical forces involved in chest compressions - Organization of resuscitation equipment and resuscitation rooms
Cognitive Ergonomics	Study of mental activity, thought processes, and how an individual makes decisions and interacts with elements of an system	- Perception of clinical parameters (e.g. heart rate, chest raise) - Factors affecting situation awareness - Decision-making and decision support tools
Organization Ergonomics	Study of group, including teams and organizations, communication, processes, structure, and culture.	- Team communication and shared mental models - Team training and teamwork metrics - NICU safety culture

Table 2.2 Situation Awareness “Demons” and Neonatal Resuscitation

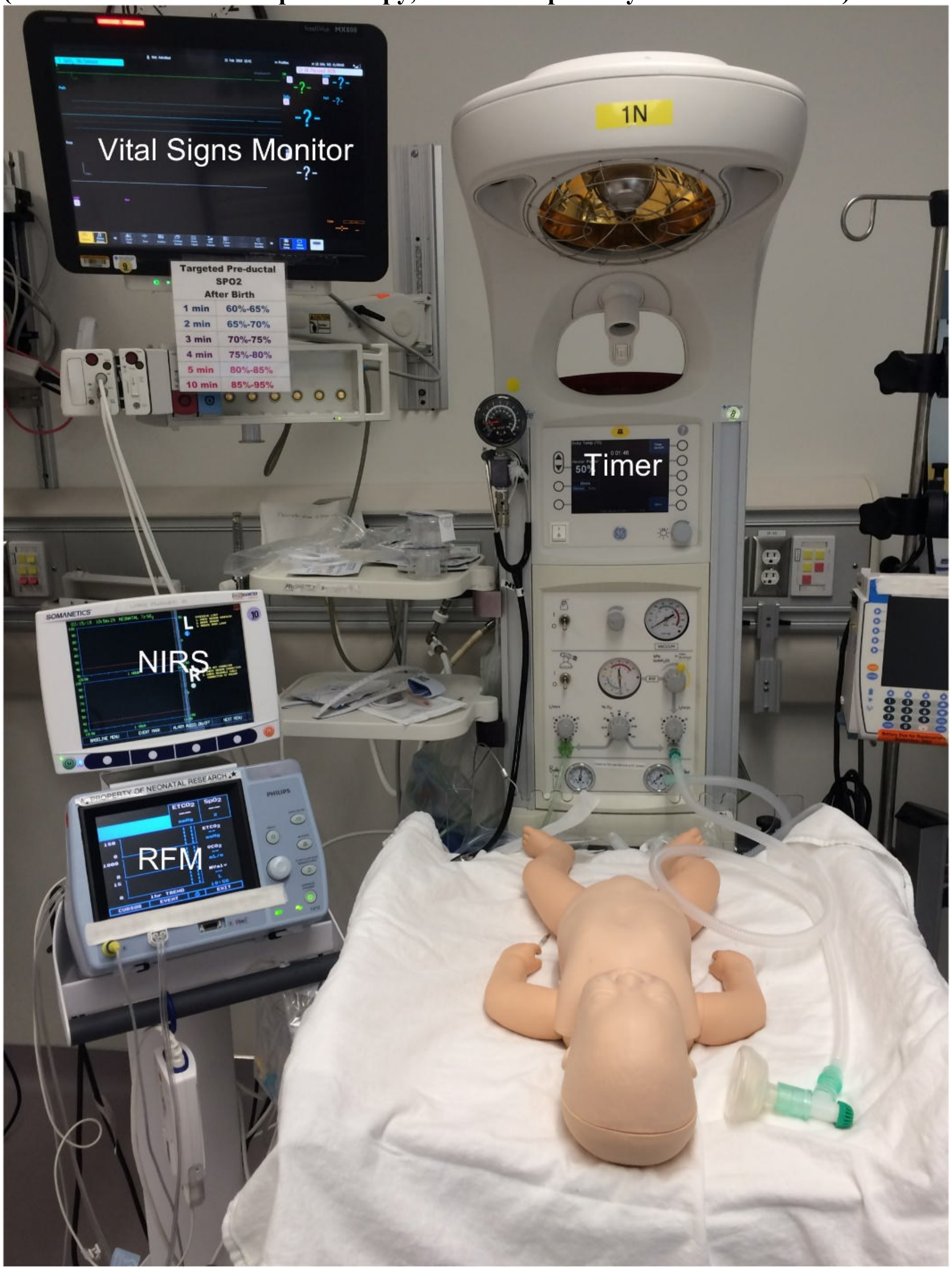
Demon	Description	Examples in Neonatal Resuscitation
Attentional Tunnelling	An individual becomes focused on one source of information or one aspect of the environment, failing to reassess the situation as a whole.	A HCP focused on trying to obtain a difficult endotracheal intubation fails to notice that the neonate’s heart rate has fallen below 60 bpm.
Requisite Memory Trap	Limitations in size and duration of working (short term) memory restricts an individual’s ability to retain all situationally relevant information.	A HCP cannot simultaneously remember all vital signs and trends, birth weight, antenatal history, and the timing and frequency of all the interventions that have been done thus far in a complex resuscitation.
Data Overload	An individual is overwhelmed by the amount of data being presented, particularly if it is disorganized.	Presence of multiple sources of data such as vital signs monitor, respiratory function monitor, NIRS data, multiple auditory alarms, and conversations from the team overwhelms a HCP’s ability to coherently process the information.
Errant Mental Model	Application of the wrong approach or general understanding to the given situation.	HCPs apply usual SpO_2 targets to a neonate with known cyanotic congenital heart disease, where the SpO_2 is not expected to be above 85%.
Misplaced Salience	An individual places more attention or importance on information or stimuli that are of minor relevance to the situation.	HCP troubleshoots a nuisance alarm (e.g. apnea alarm in a non-intubated infant) because of the loud and high-pitched sound.
WAFOS	Workload, anxiety, fatigue and other stressors that degrade cognitive functioning in multiple ways, such as degrading working memory, decreasing cognitive processing, decreasing attention, and increasing susceptibility to cognitive errors.	A tired team leader at hour 20 of a 240-hour shift, already managing a busy NICU, has difficulty directing the resuscitation of a 23 week infant not responding to bag-mask ventilation.
Complexity Creep	Increased complexity of a system or algorithm leads to decreased understanding of equipment and system function.	Incorporating NIRS targets with SPO_2 targets to neonatal resuscitation algorithm increases decision-making complexity.
Out-of-the-Loop Syndrome	Automation leads to systems changes that are done without the knowledge of human operators, leaving the operator with an incorrect assessment of the current system status.	Modern ventilators can make automatic adjustments in ventilation pressures without operator intervention. Therefore, HCPs may not be aware of current ventilation settings.

Table 2.3 Examples of Psycho-social Factors Impacting Teamwork in Neonatal Resuscitation

Factor	Possible Effects on Neonatal Resuscitation
Team Familiarity and Interpersonal Relationships	HCPs participating in neonatal resuscitation may be ad hoc, and therefore have varying levels of familiarly with one another. Team members may therefore not be as comfortable pointing out errors, or be unfamiliar with each other's level of training / expertise. Unfamiliarity with names can hinder directed communications.
Role Clarity and Leadership	When leadership and roles are not clear, resuscitation tasks and decision-making may be inefficient. For example, lack of clear leadership in neonatal resuscitation may delay decision-making for interventions such as intubation and chest compressions. Role confusion can lead to tasks not being performed when multiple team members are capable (e.g. checking for heart rate).
Stress	Stress can adversely affect interpersonal communications, leading to confusion and misunderstanding. Stress can also propagate through the resuscitation team, decreasing overall team function.
Safety Culture	Safety culture might increase HCPs' comfort with reporting errors, and increase shared sense of responsibility for improving patient outcomes.
Medical Hierarchy	While an existing medical hierarchy can help establish leadership, hierarchies can also discourage checking behavior. For example, a nurse may be more reluctant to point out an obvious mask leak to a neonatologist. Hierarchies discourage shared responsibility and open communication.

Figure 2.1 Example of Systems Analysis Model for Neonatal Resuscitation centered on bag-mask ventilation (condensed and adapted from Moray's systems analysis)

Figure 2.2 Neonatal Resuscitation Environment with Multiple Monitoring Modalities (NIRS = Near-Infrared Spectroscopy, RFM – Respiratory Function Monitor)



Chapter 3. Reorganizing Neonatal Resuscitation Equipment Improves Performance Speed Under Simulation Conditions

Brenda Law[1,2], Po-Yin Cheung[1,2], Megan O'Reilly[1,2], Caroline Fray[1,2], Georg Schmölzer[1,2]

[1]Centre for the Studies of Asphyxia and Resuscitation, Royal Alexandra Hospital, Edmonton, Canada

[2]Dept. of Pediatrics, University of Alberta, Edmonton, Canada

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3.1 Abstract.

Approximately 10% of infants will need resuscitation at birth. Resuscitations are performed by nurses, physicians, and other health care providers (HCPs) following international guidelines such as the Neonatal Resuscitation Program (NRP). Often, basic neonatal resuscitation equipment (e.g. monitoring and airway supplies) is not organized to facilitate equipment identification and retrieval, hindering HCP performance. In this study, we developed an equipment box with input from NRP-trained providers, reorganizing neonatal resuscitation equipment to improve ordering, grouping, and labeling. In a crossover simulation study, we tested HCP performance with this box against performance using a standard equipment bag. HCPs were faster in completing a simulated resuscitation scenario when using the equipment box (mean completion time 176±21.6s) compared with the standard equipment bag (192.6±20.2s) ($p<0.0001$). Despite familiarity with the standard equipment bag, all HCPs preferred the equipment box. Reorganizing basic neonatal resuscitation to improve ordering, grouping, and labeling may improve HCP performance.

3.2 Background

Approximately 10% of newborn infants will require resuscitation at birth. Resuscitations are performed by nurses, physicians, respiratory therapists, and other Health Care Providers (HCPs) and include tasks such as mask ventilation, measurement of oxygen saturation and titration of oxygen use, as well as more advanced tasks such as endotracheal intubation. The sequence of tasks and the decision-making process are standardized in international guidelines, such as the Neonatal Resuscitation Program (NRP).[4,86] The NRP also describes the equipment required[4]; however, the organization of this equipment is not standardized and may be different for each institution. Furthermore, HCPs who are less familiar with NRP sometimes initiate or assist with resuscitations of newborns[87,88]; these HCPs may be less familiar with the equipment, adding stress and potentially affecting their ability to provide these crucial initial steps.

To improve HCPs' performance in stressful resuscitation scenarios, Human Factors and Ergonomics (HF/E) principles have been successfully applied to the organization of resuscitation equipment.[89-94] Previous studies in adult[89,90], pediatric[91,92], and neonatal[93,94] literature have found that well-organized, ergonomically presented acute resuscitation equipment increases the speed of equipment acquisition and improves the performance of HCPs in simulated resuscitation scenarios. These studies are based on organization of large equipment carts, called "crash carts" or "code carts", which contain a comprehensive array of equipment including rarely used materials, such as emergency central lines and medications. In most neonatal resuscitations, only a subset of this equipment is required; this basic equipment includes different sized facemasks for mask ventilation, oxygen saturation probes, suction catheters, and intubation equipment including a laryngoscope, various sized endotracheal tubes and a CO_2 detector. Most labor and delivery units and Neonatal Intensive Care Units (NICUs) may only have one or two "crash carts" available; in contrast, basic resuscitation equipment is often kept at every bedside or radiant warmer. The best organization of this basic equipment has not been extensively studied. Also, previous studies looking at neonatal resuscitation equipment have not studied the effect of equipment organization under full resuscitation scenarios; instead, participants have been asked only to retrieve equipment and did not need to perform other clinical tasks. This added workload might have an additional effect on overall performance. An ergonomically organized basic NRP equipment kit might facilitate timely performance of initial neonatal resuscitation tasks, especially in units where it is uncommon to have a compromised newborn and staff may not be as familiar with the equipment and experience more stress.

In this study, we aimed to develop an ergonomic NRP equipment box and test its effect on HCP performance using simulated neonatal resuscitations. We hypothesized that reorganizing NRP equipment to improve ordering, grouping, and labeling will decrease the time needed to complete standard steps in a neonatal resuscitation scenario, as compared to the current local standard equipment bag.

3.3 Study Methods

3.3.1 Development of Equipment Box and Equipment Reorganization

We assessed the current equipment bag used in the Labor and Delivery Unit at Royal Alexandra Hospital, Edmonton, Canada. The standard equipment bag contains basic equipment needed for the first steps of NRP (Table 3.1) and is kept in each delivery room. Equipment is organized in unlabeled elastic-held bundles and enclosed in a disposable clear plastic bag (Figure 3.1A). HCPs in this institution are familiar with this equipment bag and use it routinely. Problems identified in this setup include: lack of labeling, loose items, and bundling of unrelated items (e.g. meconium aspirator and scissors).

Using an off-the-shelf compartmentalized plastic box, this equipment was reorganized (Figure 3.1B). Pieces of equipment were grouped together by function and placed in compartments from top to bottom in order of anticipated need. Clear labels were placed in each compartment.

3.1.2 Simulation Study Setup

Performance testing was conducted in October 2016 at the simulation lab at the Centre for the Studies of Asphyxia and Resuscitation, Edmonton, Canada. The simulation lab is equipped with state-of-the art simulation equipment, including a radiant warmer with built-in T-piece ventilation device and video recording capabilities. HCPs trained in NRP, including registered nurses, respiratory therapists, neonatal nurse practitioners, neonatal consultants and neonatal fellows were recruited from the Royal Alexandra Hospital Neonatal Intensive Care Unit (NICU). The study was approved by the Human Research Ethics Board at the University of Alberta (Pro00065363) and consent was obtained from all HCPs prior to participation.

A low-fidelity neonatal manikin (Neonatal Resuscitation Baby, Laerdal, Stavanger, Norway) capable of simulating mask ventilation and endotracheal intubation was used. The standard equipment bag and new equipment box were compared. Participants were shown both equipment sets visually but not allowed to examine them in detail prior to the simulation.

Using a crossover design, each HCP acted as an assistor in two sequential and standardized NRP scenarios, with the primary investigator acting as the lead resuscitator managing the airway in all cases (Figure 3.2). Two simple NRP scenarios were designed: Scenario 1: resuscitation of a term infant with fetal bradycardia, and Scenario 2: 36 week gestational age infant with maternal chorioamniotis. Both scenarios required the same steps to resuscitate an apneic infant with heart rate <100/min and ended when the lead resuscitator received the equipment for endotracheal intubation. Each participant was randomized to use either the standard resuscitation bag first followed by the ergonomic equipment box, or the ergonomic equipment box first followed by the standard resuscitation bag. Each participant had to complete both scenarios. Participants were instructed to obtain equipment and/or take action as requested by the investigator (e.g. retrieve and connect suction catheter, auscultate heart rate and breath sounds). A second investigator, acting as an external observer, provided timed responses to each action, to maintain standardization. To blind the primary investigator (lead resuscitator), the equipment sets were kept on a separate table hidden behind a visual shield and were not visible to the investigator during the simulation or in the video recordings.

All simulations were video-recorded for data analysis. Each video was analyzed to obtain the time required for the entire scenario, and for four equipment-related actions: i) retrieve and attach suction catheter, ii) retrieve and attach mask, iii) retrieve and apply oxygen saturation probe, and iv) retrieve and prepare intubation equipment (specific endotracheal tube size, stylet, laryngoscope and blade). Each participant also answered a post-simulation survey to obtain demographics and user preferences using a Likert scale (1=Strongly Disagree to 5=Strongly agree).

3.1.3 Sample size and Statistical Analysis

Based on a mean scenario time of 180 seconds and a crossover design, 30 participants were needed to detect a 10% difference with a power of 0.8 and a significance of 5%. Statistical analyses were carried out using a per protocol analysis, using paired *t*-tests to compare means for total scenario time. A p value of <0.05 was considered significant. Descriptive statistics were performed for each of the four equipment related actions as secondary analysis.

3.4. Results

Thirty-four HCPs were approached, and 30 HCPs participated, including neonatal consultants (n = 3), fellows (n = 4), neonatal nurse practitioners (n = 3), registered nurses (n =14), and registered respiratory therapists (n = 4). All HCPs were NRP certified within the last 2 years and 20 were familiar or very familiar with the standard resuscitation bag. In total, 26 participants completed the simulations per protocol and were analyzed; 4 completed the scenarios with protocol violations, which included three scenarios with missing equipment and one participant with inadequate orientation to the simulation environment. All survey results were collated and analyzed regardless of protocol adherence.

Overall, HCPs had a shorter mean completion time of 176±21.6s using the equipment box than with the equipment bag (192.6±20.2s) (p<0.0001). HCPs (n=12) randomized to Group 1 (equipment bag followed by equipment box) had a mean completion time of 193.2±16.1s and 163.7±14.1s respectively, (p<0.0001). In comparison, HCPs (n=14) randomized to Group 2 (equipment box followed by equipment bag) had a modest but insignificantly shorter mean completion time using the equipment box (186.7±21.6s versus 192.1±23.7s). Regardless of equipment used, the second scenario took less time to complete with a mean completion time of 178.9±24.7s compared to a mean completion time of 189.9±19.5s for the first scenario (p=0.02). While the study was not powered to detect differences in each specific task, the greatest difference between task completion times is for the first task, retrieval and attachment of the suction catheter (12.6 ± 4.4s for the equipment box and 23.7 ± 13.7s for the equipment bag) (Table 3.2).

The post-simulation survey revealed very positive responses to the equipment box. While 67% of participants were familiar or very familiar with the standard equipment bag, only 8%

found the equipment bag easy to use. In comparison, all participants found the equipment box easy to use and all participants preferred the equipment box.

3.5. Discussion

Equipment organization has been studied in adult, pediatric, and neonatal resuscitation focusing on the organization of large "code carts".[89-94] Rousek and Hallbeck[90] described the testing and design of an ergonomic adult code cart medication drawer using HF/E principles and found that improved visibility and supplies grouping reduced wasteful actions and medication retrieval times during simulation. In pediatric resuscitations, different-sized equipment is used depending on the patient size, which can be estimated from the patient length using Broselow tape. Agarwal et al.[91] compared equipment retrieval times during simulations using a standard code cart versus a Broselow tape organized cart, and reported that the Broselow tape organization resulted in faster and more accurate equipment retrieval. Subsequently, several studies have examined the use of NRP organized neonatal resuscitation carts. These carts also contained comprehensive equipment designed for use beyond basic airway management, but were designed specifically for neonatal rather than pediatric use. Chitkara et al.[94] compared equipment acquisition times using a neonatal resuscitation cart versus a generic code cart, and demonstrated 58-73% faster equipment acquisition times for complex neonatal resuscitation scenarios using the neonatal resuscitation cart. Chan et al.[93] also demonstrated faster equipment acquisition using an NRP-organized cart; however, participants were only asked to retrieve equipment independent of a resuscitation scenario and were not required to perform other clinical tasks.

In our study, we were able to demonstrate an improvement in HCP performance and a reduction in time needed to complete equipment-related tasks when basic NRP equipment was organized to facilitate identification and retrieval. Participants were asked to retrieve equipment and perform specific NRP tasks, which are more closely related to real-life resuscitations. Also, our scenarios assessed HCP performance in more common neonatal resuscitation scenarios (an apneic term or near-term infant) rather than more rare occurrences such as extreme prematurity or congenital anomalies. As performance varies from individual to individual, our crossover design enabled each participant to act as her or her own control. This resulted in a small rehearsal effect; participants were more prepared for the second scenario. This effect augmented the superiority of the equipment box, and is likely the cause for more similar scenario times for the group that used the equipment box first. Finally, while this study was not powered to detect time differences in each individual task, the first task (retrieve and attach suction catheter) appeared to benefit the most from ergonomic equipment organization. We speculate that suction catheters were harder to locate and retrieve from the equipment bag than other equipment, as the equipment bag is full at the beginning of the scenario and the suction catheter packages were difficult to identify.

Qualitatively, the equipment box was also superior in other aspects. In three scenarios where equipment was inadvertently missed during restocking, participants correctly identified missing equipment much more quickly when using the equipment box. In contrast, more time was spent searching for equipment missing from the bag before it was identified as missing and a replacement requested. Unused equipment in the box also remained clean and organized at end of the each scenario, whereas equipment from the bag was usually found scattered on the table, around the manikin, or on the floor. Finally, the equipment bag had elastic-held bundles, which some participants found difficult to unravel.

Simulation is also an effective means of analyzing equipment usability in general; we were able to identify several other ergonomic-related equipment issues during our simulations. First, plastic packaging for the disposable masks and pulse oximeters was difficult to open, particularly for less-experienced participants, causing delay and adding frustration and stress. Different-sized suction catheters were difficult to identify, as the packaging was quite similar, resulting in confusion. In other cases, intubating stylets were unintentionally bent during equipment stocking, which hindered their insertion into the endotracheal tubes, also causing frustration and delay.

3.5.1 Limitations

First, complete blinding was not possible as accessing the equipment box versus equipment bag produced different sounds; this was mitigated by i) using an external observer to maintain standardized timing during the scenario between steps not requiring participant action, and ii) performing video analysis without audio. Second, in order to maintain comparability, both scenarios were made similar and the same steps were required. As a result, there was a rehearsal effect; participants could more easily anticipate the next needed step during the second scenario. Performance testing was done in simulation only; field-testing should be conducted in the delivery room during real-life resuscitations. Finally, the study involved HCPs from the NICU; these providers may be more familiar with the NRP equipment and benefit less from ergonomically organized equipment than other HCPs, such as family physicians, midwives, obstetricians, and delivery suite nurses.

3.6. Conclusions

During simulations of common neonatal resuscitation scenarios, health care providers were able to retrieve equipment and perform equipment-related tasks faster when basic NRP equipment was reorganized to improve equipment ordering, grouping, and labeling. Despite lack of familiarity, all participants preferred the ergonomic box. Several other ergonomic equipment issues were also identified in this process. Simple reorganization of basic neonatal resuscitation equipment may improve HCPs' performance and the time of delivery of appropriate initial resuscitation steps in newborns requiring simple resuscitation.

Table 3.1 Basic NRP equipment

Masks for Non-invasive ventilation / CPAP
50mm Neonatal Resuscitation Mask
42mm Neonatal Resuscitation Mask
Suction Catheters
8 Fr
10 Fr
Neonatal Pulse Oximeter
Endotracheal Tubes and Stylet
2.5, 3, and 3.5mm uncuffed endotracheal tubes
6Fr intubating stylet
Laryngoscope and Miller 1 Blade
Miscellaneous Equipment
CO2 detectors
Meconium Aspirator
Medical Tape
Umbilical Cord Clamp and Scissors

Table 3.2 Summary of Results

	Task	Mean Time to Complete Task (seconds ± SD)		P value[1]
		Using Ergonomic Equipment Box	Using Standard Equipment Bag	
Combined (n = 26)	**Total completion time**	176.1 ± 21.6	192.6 ± 20.2	< 0.0001
	Retrieve and attach suction catheter	12.6 ± 4.4	23.7 ± 13.7	0.0005
	Retrieve and attach mask	13.1 ± 3.0	14.7 ± 4.35	0.0821
	Retrieve and apply oxygen saturation probe	20.8 ± 4.9	25.3 ± 5.9	< 0.0001
	Retrieve and prepare intubation equipment	39.3 ± 6.2	44.9 ± 8.0	0.0039
Group 1 Using Bag in 1st scenario (n = 12)	**Total completion time**	163.7 ± 14.1	193.2 ± 16.1	< 0.0001
	Retrieve and attach suction catheter	13.4 ± 2.3	28.0 ± 19.4	0.0186
	Retrieve and attach mask	11.6 ± 2.4	15.5 ± 4.0	0.0012
	Retrieve and apply oxygen saturation probe	21.1 ± 5.8	23.5 ± 4.5	0.0208
	Retrieve and prepare intubation equipment	35.8 ± 5.6	44.2 ± 6.9	0.0013
Group 2 Using Box in 1st scenario (n = 14)	**Total completion time**	186.7 ± 21.6	192.1 ± 23.7	0.0927
	Retrieve and attach suction catheter	17.7 ± 6.4	20.0 ± 3.2	0.1315
	Retrieve and attach mask	14.5 ± 2.9	14.0 ± 4.7	0.7233
	Retrieve and apply oxygen saturation probe	20.5 ± 4.3	26.9 ± 6.7	0.0002
	Retrieve and prepare intubation equipment	42.3 ± 5.0	45.4 ± 9.2	0.2627

[1] Based on paired t-test

Figure 3.1 Equipment sets compared including a) Standard Equipment Bag and b) Ergonomic Equipment Box

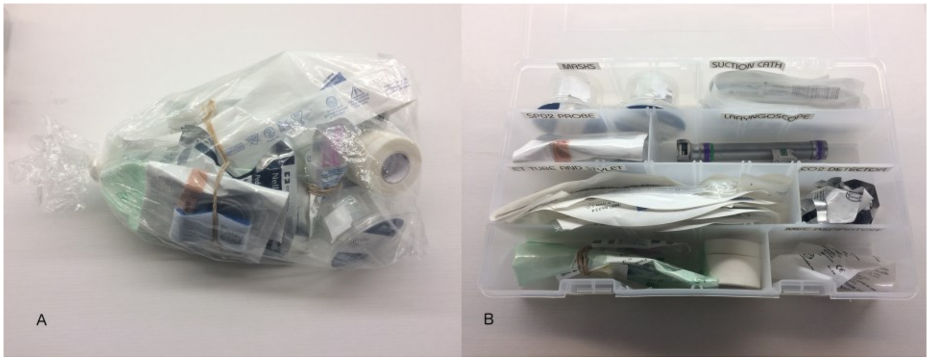
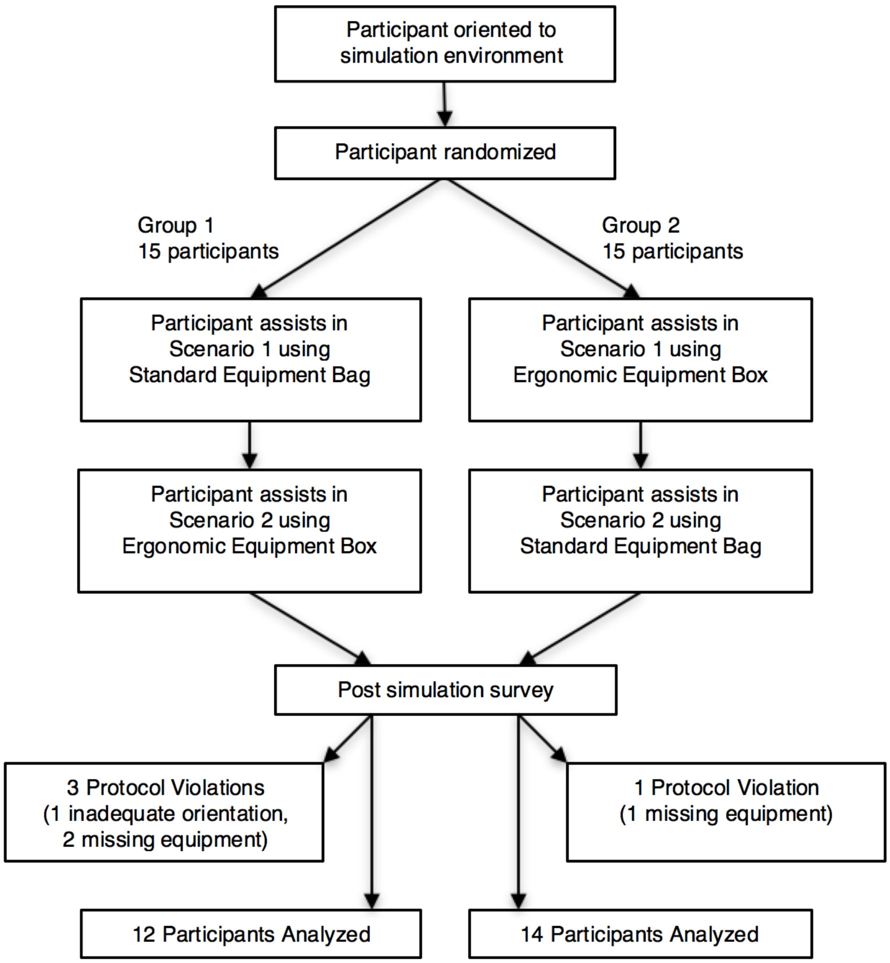


Figure 3.2 Study Design and Participants



Chapter 4. Analysis of Neonatal Resuscitation Using Eye-Tracking – A Pilot Study

Brenda Hiu Yan Law MD[1,2], Po-Yin Cheung MBBS PhD[1,2], Michael Wagner MD[1,3], Sylvia van Os RRT[1], Bin Zheng MD PhD[4], Georg Schmölzer MD PhD[1,2]

[1]Centre for the Studies of Asphyxia and Resuscitation, Royal Alexandra Hospital, Edmonton, Canada

[2]Dept. of Pediatrics, University of Alberta, Edmonton, Canada

[3]Dept. of Pediatrics, Medical University of Vienna, Vienna, Austria

[4]Dept. of Surgery, University of Alberta, Edmonton, Canada

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4.1 Abstract

Background: Eye-tracking can be used to analyse visual attention (VA) of health care providers during clinical tasks. No study has examined eye-tracking during in neonatal resuscitation.

Objective: To test the feasibility of eye-tracking to examine VA during neonatal resuscitation.

Methods: Six video-recordings were obtained using eye-tracking glasses worn by resuscitators during the first five minutes of neonatal resuscitation. Videos were analyzed to obtain i) areas of interest (AOIs), ii) duration spent on each AOI, and iii) frequency of saccades between each AOI.

Results: Five videos were of acceptable quality and analysed. Overall, 35% of VA was directed at the infant, with 33% of VA directed at patient monitors and gauges. There were 0.45 saccades/sec and most saccades involved patient monitors.

Conclusion: During neonatal resuscitation, saccades are frequent, and VA is often directed away from the infant towards patient monitors. Eye-tracking can be used to analyse human performance during neonatal resuscitation.

4.2 Introduction

The Joint Commission on Accreditation of Healthcare Organizations highlighted that failures in providing effective neonatal resuscitation account for more than two thirds of perinatal mortality and morbidity.[2] To reduce neonatal mortality and morbidity, international organizations have emphasized the need to study human performance during neonatal resuscitation.[5]

Health care provider (HCP) performance is a complex interplay of many factors including perception, attention, memory and knowledge, decision-making, communication, teamwork, and motor skills. Thus, the study of HCP performance requires a complex 'toolbox' of assessment methods. One such tool is eye-tracking, which has been used in other industries including commercial aviation and consumer marketing to study visual attention (VA). Eye-tracking glasses continuously record participants' visual fixation and shifts in gaze (saccades). This data is then analyzed to elucidate information such as areas of interest (AOI), percentage of time spent on each AOI, and types and frequency of saccades. Within medicine, eye-tracking technology has been successfully applied in areas such as nursing, surgery, radiology, and anaesthesia.[18,95]

Despite improvements in technology and education, neonatal resuscitation remains a demanding and stressful endeavor for HCPs. Even for experienced clinicians, effective neonatal resuscitation requires the resuscitator's attention on many tasks (e.g. mask ventilation, observing monitors, coordinating team tasks, and making decisions). The break-up of this attention and its correlation to neonatal resuscitation performance is not well understood. Further, changes in practice, such as increasing use of electrocardiogram for heart rate monitoring, may have an unintended impact on HCP attention and performance. Eye-tracking has been successfully used to analyse VA in other health care areas and might be applicable to neonatal resuscitation. Therefore, we aimed to test the feasibility of using eye-tracking technology to analyse HCPs' VA during neonatal resuscitations in the delivery room.

4.3 Methods

As a pilot, six specialised video-recordings were obtained using head-mounted eye-tracking glasses (Tobii Glasses, Tobii Technology, Inc., Falls Church, VA). Participants were HCPs recruited from a tertiary neonatal intensive care unit. During each resuscitation, the participant stood at the head of the resuscitation warmer and managed the airway while leading the team. Eye-tracking glasses recorded visual fixations as red markers integrated into video recordings. The videos were manually analysed to obtain i) AOIs, ii) duration spent on each AOI (fixation) and iii) frequency of saccades (rapid shifts in visual focus) performed during entire resuscitation, and iv) frequency of saccades between each AOI. The first five minutes of each video were analysed, representing the most active phase of each resuscitation. The study was approved by the Human Research Ethics Board, University of Alberta, and parental written consents were obtained to use the video recordings.

4.4 Results

All six videos were reviewed by two investigators (BL and GMS); five videos were of acceptable quality and were analysed. The sixth video had > 50% visual fixation data missing from the recording due to poor calibration and was excluded from analysis. Results from the remaining recordings are summarised in Table 4.1. Infants had a mean(SD) gestation and birth weight of 28(3) weeks and 1296(402)g. The median (IQR) Apgar scores at one and five minutes were 5(3-6) and 8(7-9), respectively. Four infants received mask ventilation and one infant received endotracheal intubation and the emergency placement of an umbilical venous catheter. During the first five minutes of resuscitation, an average of 35(8)% of VA was directed at the infant, 33(10)% focused on displays and gauges and 18(5)% spent in transition between AOIs. Only 5(3)% of time was directed towards other HCPs. When displays and gauges integrated on the radiant warmer (including Apgar timer and T-piece pressure gauges) were separated from peripheral displays (including vitals signs monitors and flow sensors), HCPs were found to dedicate more time focusing on peripheral displays (26%). In the infant requiring intubation, 44% of VA was directed at the infant, with 21% of time directed at the displays and gauges.

There were frequent saccades in all cases, with a mean of 0.45 saccades/sec (i.e. approximately 1 every 2 sec). When endotracheal intubation was needed, shifts in gaze were less frequent with 0.33 saccades/sec (1 every 3 sec). When saccades were analysed with respect to AOIs, 53% of saccades were to or from peripheral displays (pulse oximetry, electrocardiogram and respiratory flow sensors). Percentage time devoted to each AOI and percentage saccades are represented graphically in Figure 4.1.

4.5 Discussion

In a simulated scenario, VA is directed in 20% of time at patient monitors during uneventful anaesthesia induction; in comparison, once a critical incident occurs, VA focused on patient monitors increases to 30%.[95] This increase during critical incidents suggests that these patient monitors play an important role in the maintenance of adequate situation awareness. To our best knowledge, eye-tracking technology to assess VA during neonatal resuscitation has not been previously studied. We observed that HCP's VA was only directed towards the infant in 35% of time. Similar to the report by Schulz et al.[95] we observed that in 33% of time, HCP's VA was directed at patient monitors.

Furthermore, we observed that during mask ventilation HCPs often moved their gaze to or from a patient monitor to assess the effectiveness of their ventilation. In fact, half of observed saccades (53%) involved moving to or from peripheral displays. This represents a significant cognitive demand. This high cognitive demand might be related to the current neonatal resuscitation guidelines, which recommend continuous monitoring of patient's condition using pulse oximetry and electrocardiogram.[96] As more emphasis is directed on monitoring, visual displays will play a more prominent role during neonatal resuscitation. Therefore, the impact of these visual displays on HCP performance, including VA and situation awareness, requires further study.

Visual attention of HCPs during neonatal resuscitation might be further impacted by mental workload or the performance of different tasks. For example, in this study, VA directed at the infant increased during resuscitation when endotracheal intubation was performed compared to resuscitation with mask ventilation alone (44% vs 35%, respectively). In addition, saccades were less frequent as the HCP was primarily focused on establishing an airway. While expected, this change in behavior might have an impact on a HCPs ability to remain aware of important parameters (e.g. an infant's heart rate and oxygen saturation).

4.6 Limitations

This is a pilot feasibility testing study in which we only analysed five video recordings. One of six recordings was excluded because of poor quality, which is similar to the proportion of unusable data as previously reported.[18,96] Second, visual fixation analysis alone does not account for the phenomenon of inattentional blindness. To assess a HCP's perception and comprehension of the clinical information, a measure of situation awareness is required. Finally, there is high variability between the observations, reflecting that VA in general is highly variable depending on workload, types of tasks, interpersonal differences, and other factors.

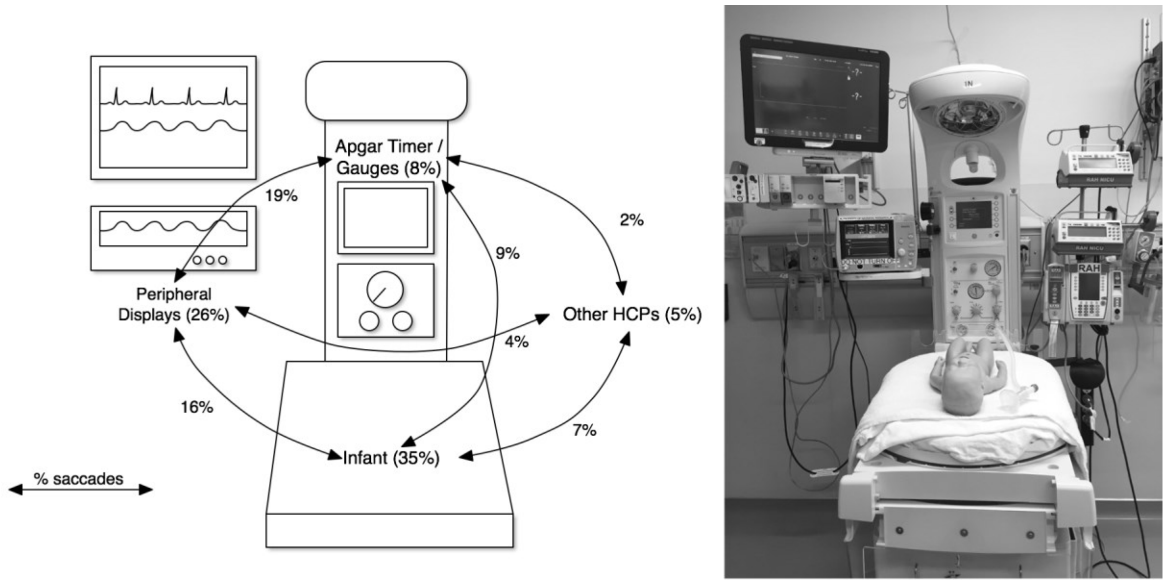
4.7 Conclusion and Future Directions

Eye-tracking can be used to examine visual attention of health care providers during neonatal resuscitation. In this pilot study, visual attention was equally distributed between monitors and the infant. However, overall a significant proportion of visual attention was directed away from the infant and towards peripheral patient monitors. Future studies utilizing eye-tracking data in conjunction with other assessment tools should be performed to examine factors affecting human performance during neonatal resuscitation.

Table 4.1 Summary of Results

		Recordings					Combined	
		1	**2**	**3**	**4**	**5**	**Mean**	**SD**
Interventions Performed		Mask Ventilation	Mask Ventilation	Mask Ventilation	Mask Ventilation	Intubation UVC		
% Time Focused on Each Areas of Interest (AOI)	**Infant**	29%	40%	26%	38%	44%	35%	8%
	Displays and Gauges (Total)	43%	24%	42%	33%	21%	33%	10%
	Apgar Timer and Gauges	9%	4%	12%	14%	3%	8%	5%
	Peripheral Monitors (Vitals signs and flow sensor)	34%	24%	30%	19%	22%	26%	6%
	Other Health Professionals	1%	6%	8%	3%	6%	5%	3%
	Transition / Shifting gaze	25%	14%	20%	20%	13%	18%	5%
	Other	1%	2%	5%	7%	1%	3%	3%
	No Data	0%	13%	1%	2%	16%	7%	7%
	Saccades per second	0.53	0.36	0.51	0.51	0.33	0.45	0.1

Figure 4.1 Diagram representing % visual attention directed at different AOIs in the resuscitation environment and frequency of saccade types



Chapter 5. Assessment of Visual Attention and Situation Awareness during Neonatal Resuscitation: A Randomized Simulation Study

Brenda H. Law[1,2], MD, Po-Yin Cheung, MBBS PhD[1,2], Sylvia van Os, RRT[1], Caroline Fray, RN[1,2], Georg M. Schmölzer, MD PhD[1,2]

[1]Centre for the Studies of Asphyxia and Resuscitation, Royal Alexandra Hospital, Edmonton, Canada

[2]Department of Pediatrics, University of Alberta, Edmonton, Canada

5.1 Abstract

Objectives: To assess the use of Situation Awareness Global Assessment Tool (SAGAT) and to compare situation awareness (SA), visual attention (VA), and protocol adherence in simulated neonatal resuscitations using two different monitor positions.

Design: Randomized controlled simulation study

Settings: Simulation lab at the Royal Alexandra Hospital, Edmonton, Canada.

Participants: Healthcare providers (HCPs) with Neonatal Resuscitation Program certification within the last 2 years and trained in neonatal endotracheal intubations.

Intervention: HCPs were randomized to either central (eye-level on the radiant warmer) or peripheral (above eye-level, wall-mounted) monitor positions. Each led a complex resuscitation with a high-fidelity mannequin and a standardized assistant. As per SAGAT, simulations were paused at 3 predetermined points, with five questions asked each pause. Videos were analyzed for SAGAT and adherence to a Neonatal Resuscitation Program (NRP) checklist. Eye-tracking glasses recorded participants' VA.

Main outcome measure: The main outcome was SA as measured by composite SAGAT score. Secondary outcomes included VA and adherence to NRP checklist.

Results: Thirty simulations were performed; 29 were completed per protocol and analyzed. Twenty-two eye-tracking recordings were of sufficient quality and analyzed. Median composite SAGAT was 11.5/15 central vs. 11/15 peripheral, p=0.56. Checklist scores 46/50 central vs. 46/50 peripheral, p=0.75. Most VA was directed at the mannequin (30.6% central vs. 34.1% peripheral, p=0.76), and the monitor (28.7% central vs. 20.5% peripheral, p=0.06.)

Conclusions: Simulation, SAGAT, and eye-tracking can be used to evaluate ergonomics of neonatal resuscitation. During simulated neonatal resuscitation, monitor position did not affect SA, VA, or protocol adherence.

5.2 Introduction

The Neonatal Resuscitation Program (NRP) provides a standardized algorithm for health care providers (HCPs), where sequential actions are recommended based on ongoing assessment of the newborn infant.[4,86] Critical clinical parameters are obtained by direct observations and by continuous monitoring of heart rate (HR) and oxygen saturation (SpO_2) using electrocardiography (ECG) and pulse oximetry. Thus, HCPs are increasingly reliant on information displayed on monitors for decision-making during neonatal resuscitation. While monitoring displays provide vital information, they have not been optimized for ease of use. We previously reported that HCPs spend nearly 1/3 of their time focusing their visual attention (VA) on vital signs monitors during delivery room resuscitations.[47] Since these displays are not readily within a HCPs field of view, recognition of vital sign changes may be delayed, causing HCPs' to lose situation awareness (SA). SA is "the perception of the elements in the environment and the comprehension of their meaning and the projection of their status into the future."[42] It is an internal construct that can be difficult to assess by observation alone. Through simulation, SA evaluation methods, such as Situation Awareness Global Assessment Tool (SAGAT)[97], can be tested. SAGAT has been adapted for use in simulated medical scenarios, although it has never been used for neonatal resuscitation.[97-100]

We aim to assess if SAGAT can be used to objectively measure SA during simulated neonatal resuscitations. We further hypothesized that a centrally positioned monitor, compared to peripherally positioned, would result in better SA, less fragmented VA, and better NRP performance. Therefore, using SAGAT and eye-tracking, we compared overall SA, VA, NRP checklist scores, and participant satisfaction during simulated neonatal resuscitations with two different monitor positions.

5.3 Methods

This study was carried out between October and December 2017 at the Centre for the Studies of Asphyxia and Resuscitation, Royal Alexandra Hospital, Edmonton, Canada. The Royal Alexandra Hospital Research Committee and the Health Ethics Research Board, University of Alberta (Pro00071387) approved the study, and written informed consent was obtained. All participants were recruited by using Health Ethics Research Board-approved study posters, displayed throughout the NICU through the study period. HCPs who were NRP certified within the last 2 years and trained in neonatal endotracheal intubations were included. Exclusion criteria were expired NRP registration or any medical condition contraindicating the exertion required during simulated neonatal resuscitation.

5.3.1 Sample size and randomization

For this pilot study, we studied composite SAGAT score (number of correct SAGAT responses, max score 15) as the primary outcome, with a convenient sample size of 30 HCPs, the minimal suggested sample size for SAGAT.[50] Each participant was randomized to either central (at eye-level on the radiant warmer) or peripheral (~6 feet height, left of the warmer, wall mounted) monitor position (Figure 5.1) using sealed opaque envelopes containing randomization cards generated using an online randomizer (http://www.randomizer.org) by an assistant outside of the research team.

5.3.2 Study Equipment

We used a high-fidelity neonatal mannequin (Newborn HAL, Gaumard Scientific, Miami, FL), which can simulate cyanosis, respiratory effort, breath sounds, and pulses, and allows mask ventilation and endotracheal intubation. The mannequin was placed on an adjustable radiant warmer (Giraffe Incubator, General Electric Healthcare, Burnaby, Canada) to allow participants to adjust table height. Vital signs including HR, SpO_2, and respiratory rate were displayed on a simulated vital signs monitor using a portable tablet computer synchronized with the mannequin. Each participant was fitted with mobile, head-mounted eye-tracking glasses (Tobii Glasses, Tobii Technology, Inc, Falls Church, Virginia, USA) to record their VA. Eye-tracking glasses use reflected infrared light to track pupillary movement and imaging processing to incorporate gaze patterns as markers into video from a participant's viewpoint.[18,47]

5.3.4 Situation Awareness Global Assessment Tool (SAGAT) Design

During SAGAT, each simulation is paused multiple times and participants are asked a group of predetermined questions at each pause to assess SA at three levels.[42,50] Level 1 SA is *perception* of the elements in the environment (e.g., awareness of patient's HR or SpO_2, actions of other team members, or awareness of equipment function). Level 2 SA involves the *comprehension* of the significance of elements in the environment, combining data to form a holistic picture of the situation considering one's goals. During resuscitations, HCPs would combine clinical information to determine stability and possible diagnosis. Level 3 SA, the highest level, is to *project* the future status of these elements, through a combination of perception of the current status, comprehension of the situation (level 1 and level 2 SA), and expert knowledge and experience.[50] The answers are compared to real data according to the designed simulation, actual participant actions, and experts' interpretations of the meaning of that data to provide an objective measure of SA. One important aspect of SAGAT is the development of questions for the experiment, which requires an understanding of an individual's role in the scenario.

To develop SAGAT questions specific to neonatal resuscitation, we first analyzed the NRP algorithm using Goal Directed Task Analysis.[101] One major goal and six sub-goals were identified. Subsequent analysis of the SA requirements for each sub-goal led to the development of Level 1 (perception), Level 2 (comprehension) and Level 3 (projection) questions. Based on the design of practice and study simulation scenarios, four SAGAT question groups, or queries, were generated, each containing three Level 1 questions, one Level 2 question, and one Level 3 question (Table 5.1).

5.3.5 Simulations Procedure

The study was divided into two steps: a *practice simulation* and a *study simulation.* Prior to the *practice simulation,* participants were randomized to either central or peripheral monitor position. During the *practice simulation,* participants led the resuscitation of a 34-week infant with respiratory distress, using bag-mask ventilation and corrective steps. This step familiarized participants with the simulation environment, monitor position, the eye-tracking glasses, and SAGAT format. The *practice simulation* was not included in the analysis.

The participants were then instructed to prepare for the *study simulation*. During the *study simulation,* participants led the resuscitation of a term infant with severe bradycardia, which required intubation and chest compressions. Each HCP acted as the team leader and airway manager positioned at the head of the radiant warmer, with a co-investigator acting as their standardized assistant (CF, SvO). The assistant performed inadequate chest compressions (poor technique and slow compression rate) to increase participant workload. To test for inattentional blindness, near the end of the simulation the infant would unexpectedly deteriorate to simulate a displaced endotracheal tube, while the standardized assistant asked distracting questions regarding post-resuscitation care. Each scenario was paused at three predetermined points (i.e. during initial bag-mask ventilation, during chest compressions, and during later deterioration) and the HCP was asked five SA questions at each pause (Table 5.1). Finally, participants answered a post-simulation questionnaire to obtain demographics and user preferences using a Likert scale (1=Strongly Disagree to 5=Strongly agree).

5.3.6 Data Processing and Statistical Analysis

All simulations were video-recorded to analyze SAGAT responses and participants' performance using a NRP megacode checklist modified for the scenario.[67] Eye-tracking recordings of adequate quality (gaze capture >60%) were analyzed using a combination of manual analysis and Tobii Lab analyzer software to assess VA. VA measures include i) predefined Areas of Interest (AOIs) (e.g., mannequin, vital signs monitor, T-piece pressure gauge, Apgar timer); ii) cumulative time spent on each AOI, describing VA distribution; iii) frequency of saccades, a marker of cognitive loading and VA fragmentation; and iv) monitor hit rate, or how frequently VA was directed at the monitor. VA was also analyzed separately for each major task including i) initial steps and bag-mask ventilation, ii) preparation for, during, and after intubation, iii) chest compressions, and iv) post-resuscitation stabilization. Finally, all post-simulation questionnaires were analyzed regardless of protocol adherence.

The data are presented as mean (standard deviation (SD)) for normally distributed continuous variables and median (interquartile range (IQR)) when the distribution was skewed. The data were compared using Student's t-test for parametric and Mann-Whitney U-test for nonparametric comparisons of continuous variables, and χ^2 for categorical variables. P-values are 2-sided and $p<0.05$ was considered statistically significant. Mixed ANOVA was used to compare VA during different phases of resuscitation between the two groups. Correlations were determined using Pearson product moment correlation. Statistical analyses were performed with SPSS 25 (IBM, Armonk, New York, USA).

5.4 Results

Thirty-seven HCPs responded to the study posters and 30 HCPs consented to participate [advance registered nurses (n=6), and registered respiratory therapists (n=6), neonatal nurse practitioners (n=5), clinical associate physicians (n=2), neonatal fellows (n=7), and neonatal consultants (n=4)]. Participants had a median (IQR) of 8 (6.5) years of experience in neonatal resuscitation, which was similar in both groups (p=0.59). Twenty-nine participants completed the simulations per protocol and were included in the final analysis; one was excluded for mannequin failure (central group). Scenario duration was 348 (49)sec (excluding the simulation pauses). Twenty-two participants had acceptable quality eye-tracking recordings (gaze capture >60%), and were included in VA analysis (Figure 5.2).

5.4.1 SAGAT and NRP Adherence

The mean (SD) length of pauses for SAGAT questions was 56 (16)sec. Overall, there was no difference in median composite SAGAT scores between central or peripheral monitor position (11.5/15 vs. 11/15) (Table 5.2). Similarly, we observed no difference between groups in Level 1 SA (7/9 vs. 7/9), Level 2 SA (3/3 vs. 3/3), or Level 3 SA (2.5/3 vs. 2/3). We observed no difference between SAGAT scores under different tasks and workload. The most common incorrectly answered questions were i) the current Apgar time (11/29 correct responses) and ii) HR during the unanticipated deterioration (13/29 correct responses). No correlation was found between composite SAGAT scores and years of experience (r=0.21, p=0.29), between composite SAGAT scores and percent VA directed at monitors (r=0.38, p=0.09), or between composite SAGAT scores and NRP Checklist scores (r=0.016, p=0.94).

There was no difference in NRP adherence when assessed using the modified NRP checklist (median 46/50 for both groups, p=0.75).

5.4.2 Visual Attention

Percentage time spent in each AOI was similar between groups, with most VA directed at the infant (31% central vs. 34% peripheral, p=0.76), followed by the monitors (29% central vs. 21% peripheral, p=0.06) and in transition between AOIs (10% central vs. 13% peripheral, p=0.14). There was a trend towards more VA directed at the monitor in the central position group, although this was not statistically significant (Table 5.2). Overall, there was high individual variability in VA distribution.

Monitor hits were frequent; participants had 44 (14) looks at monitor for the duration of the test simulation, or a look at the monitor every 9 (4) seconds. Monitor hit rates were similar between the two groups (0.14 and 0.12 monitor hits per second for central and peripheral position, respectively).

When separated by task, we observed no differences in VA distribution or frequency of saccades between central and peripheral position groups ($F<1$). However, there was a significant effect of task being performed on frequency of saccades, $F(1,20)=14.2$, $p=0.001$, with the most saccades during initial steps / bag-mask ventilation, and the least during chest compressions. There was also a significant effect of task being performed on the percent of VA focused on the mannequin ($F(1,20)=18.1$, $p<0.0005$), with the least VA focused on the mannequin in the stabilization phase (post chest compressions) (Figure 5.3).

5.4.2 Participant Survey

All participants found the scenario realistic. All participants in the central position group found the monitor position convenient, compared with only 8/15 of the participants in the peripheral group. Most participants did not find pausing the simulations to ask SA questions intrusive (21/30) and most (21/30) did not think that the simulation pauses affected their performance.

5.5 Discussion

To our knowledge, this is the first study examining SA and VA during simulated neonatal resuscitations using eye-tracking technology and SAGAT. We used a simple ergonomic change – monitor position – as a proof of concept. Overall, we observed no difference in SA, VA, or adherence to NRP protocol in experienced HCPs. SA, which refers to a person's perception, understanding, and anticipation of their dynamic environment, is critical in decision-making during real-life resuscitation. Therefore, assessment of SA may be more sensitive than traditional performance measures such as checklists. Previous studies examining SA during real-life resuscitation in the delivery room reported that HCPs regardless of level of training (e.g., experienced (neonatal consultants) vs. inexperienced (residents) are unable to accurately assess tidal volume delivery or chest rise during mask ventilation.[44,45]

SAGAT is one method to measure SA and has been successfully used in medical students[97], trauma[98,99], and obstetric emergencies[100]. During SAGAT, simulation pauses are required to assess SA; overall, two-thirds of participants found these pauses neither disruptive nor did they believe it affected their performance. One major challenge in SAGAT involves the design of higher-level questions. Absolute accuracy in lower level SAGAT questions may not be required for HCPs to anticipate the clinical situation (e.g., persistently low HR may prompt endotracheal intubation and chest compressions, regardless of other clinical parameters). Also, anticipatory questions (Level 3) were occasionally misinterpreted (3/30) as the clinical condition the participant "hoped" would be in the future, requiring investigator clarification. Finally, simulation pauses and SAGAT questioning technique may also be adapted for use in simulation-based education to teach neonatal resuscitation specific SA.

Eye-tracking can be used to assess and quantify VA as a measure human performance within clinical settings.[18,47,95,102-105,113] However, there is lack of data of VA during neonatal resuscitation. We previously reported that HCPs spent a significant amount of VA focused on vital signs monitors during delivery room resuscitations[47], with a similar VA pattern distribution in the current study regardless of monitor position. The relationship between VA, decision-making, and overall resuscitation performance remains unclear.

VA distribution and frequency of saccades varied widely between individuals and between resuscitation tasks. In general, saccades were frequent and VA divided between the infant and the monitoring display. This suggests that VA is easily fragmented during neonatal resuscitation. Additional monitoring such as respiratory function monitoring may add to this fragmentation and cognitive loading.

There are several limitations. We were unable to validate SAGAT due to the lack of a gold standard in assessing SA in neonatal resuscitation. Further refinement of the SAGAT queries might result in clearer participant responses for higher-level questions. There might be a Hawthorne effect; during the test simulation, participants were aware that they would be stopped and questioned, and therefore could have paid closer attention to numbers such as HR. The majority of participants were experienced HCPs; novices might have yielded different results. These HCPs are also familiar with the peripheral monitor position, which is standard in our institution. The scenario involved only two HCPs; during extensive neonatal resuscitation potentially more HCPs are involved, which could cause more obstruction of a peripherally positioned monitor, as well as more distractions leading to degraded SA.

5.6 Conclusion

Hi-fidelity simulation, SAGAT, and eye-tracking can be used in combination to evaluate ergonomics of neonatal resuscitation. During simulated neonatal resuscitation, experienced HCPs found central monitor position more convenient. However, monitor positioning did not affect HCP performance including accuracy of responses to situation awareness questions, visual attention, or adherence to NRP protocol. Visual attention was affected more by individual variation and task being performed.

Table 5.1 Situation Awareness Global Assessment Tool for Neonatal Resuscitation

Pause	Level	Question	Correct Response
Practice simulation	1	What is the Apgar timer at?	Within 30sec of timer
	1	What is the baby's SpO_2?	±5% of actual SpO_2
	1	What is your assistant currently doing?	Current Action
	2	Is the infant's SpO_2 appropriate for age?	Yes
	3	What is your next step?	Wean FiO_2 if > 21%
Test Simulation	1	What is the baby's colour?	Blue / Cyanotic
Pause #1	1	What is the baby's HR?	±10/min of actual HR
	1	What is your assistant currently doing?	Current Action
During Corrective	2	Has your corrective steps been adequate?	No
Steps for Bag-mask Ventilation (Medium Workload)	3	What is your next step?	Intubation
Test Simulation	1	What is the baby's current SpO_2?	±5% of actual SpO_2
Pause #2	1	What is the current Apgar timer at?	Within 30 sec
During chest	1	Which method is chest compression being done?	2 finger
compressions	2	Are chest compressions adequate?	No
(High Workload)	3	What do you anticipate the HR to be in 1 minute if current management continued?	<60/min
Test Simulation	1	What is the assistant currently doing?	Current Action
Pause #3	1	What is the baby's current FiO_2?	±5% of actual FiO_2
	1	What is the baby's current HR?	±10/min of actual HR
Stabilized post chest compression with acute	2	What is the baby's current clinical status?	Deteriorating after stopping chest compressions
deterioration (Low Workload, testing for inattentional blindness)	3	What do you anticipate the SpO_2 to be in 1 minute if current management is not changed?	Current SpO_2 or lower if adjustments have NOT been made Higher than current to normal SpO_2 if adjustments have been made

Table 5.2 Summary of Results

Performance Measures		Monitor Position: Central Monitor Position (Median, IQR)	Monitor Position: Peripheral Monitor Position (Median, IQR)	P-value
Composite SAGAT Score (max 15)		11.5 (3)	11 (3)	0.56
Level 1 SAGAT (max 9)		7 (1)	7 (1)	0.81
Level 2 SAGAT (max 3)		3 (1)	3 (1)	0.68
Level 3 SAGAT (max 3)		2.5 (1)	2.0 (2)	0.81
SAGAT – Pause 1 (max 5)		5 (1)	4 (1)	0.50
SAGAT – Pause 2 (max 5)		4 (1)	4 (1)	0.65
SAGAT – Pause 3 (max 5)		4 (2)	3 (2)	0.40
NRP Checklist Score (max 50)		46 (2.5)	46 (3.5)	0.75
% Visual Attention	Infant	30.6 (14.5)	34.1 (6.7)	0.76
	Monitor	28.7 (16.)	20.5 (10.8)	0.06
	Transition	10.0 (3.1)	12.1 (1.7)	0.14
	T-piece gauges	3.0 (2.2)	4.0 (1.9)	0.45
	Oxygen Blender (FiO_2)	3.1 (2.2)	5.6 (4.8)	0.14
	Apgar Timer	1.7 (1.2)	1.9 (1.4)	0.58
	Standardized assistant	4.3 (2.3)	3.2 (3.2)	0.22
	Warmer and Equipment	5.8 (1.9)	6.3 (2.6)	0.87
	Other	0.9 (0.9)	1.9 (1.7)	0.09
Saccades per second		0.65 (0.18)	0.66 (0.19)	1.0
Monitor hit rate		0.14 (0.05)	0.12 (0.05)	0.40
Number of AOIs		14 (1)	15 (2)	0.20

Figure 5.1 Schematic of Central vs. Peripheral Vitals Monitor Position in Simulation Environment

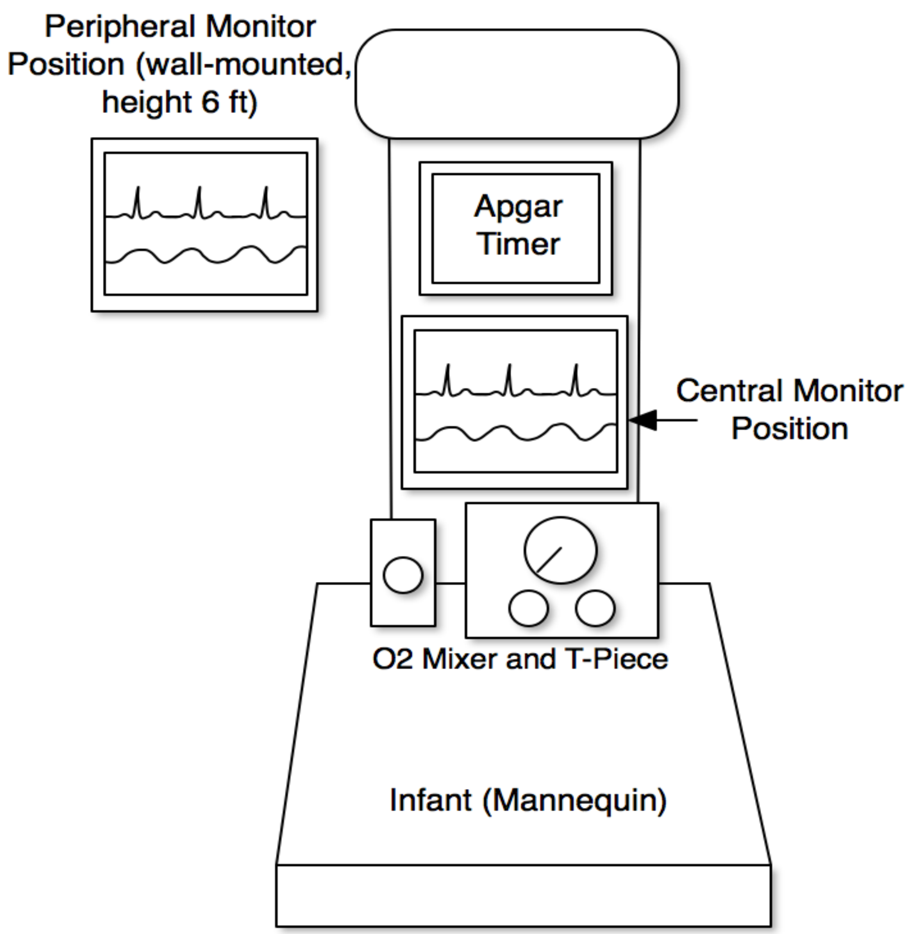


Figure 5.2 Participant Flow Diagram

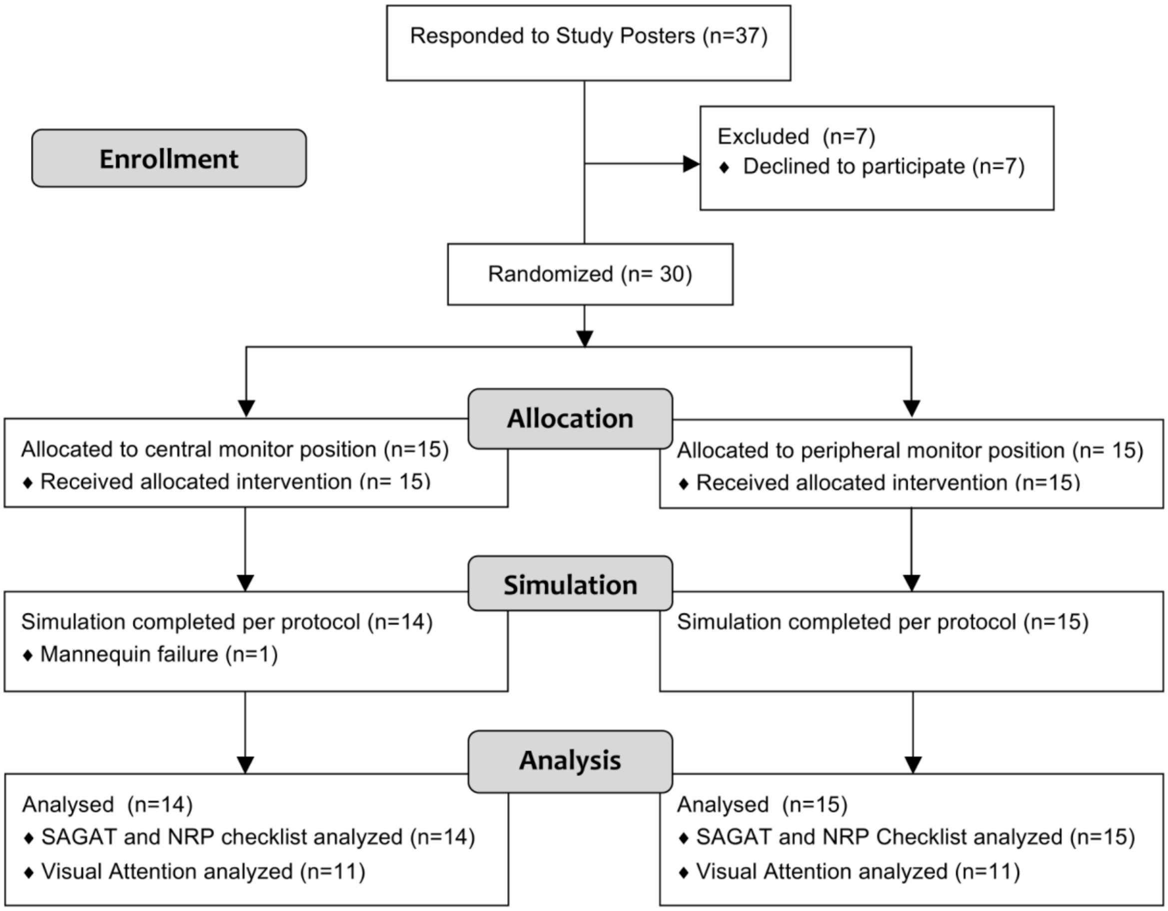
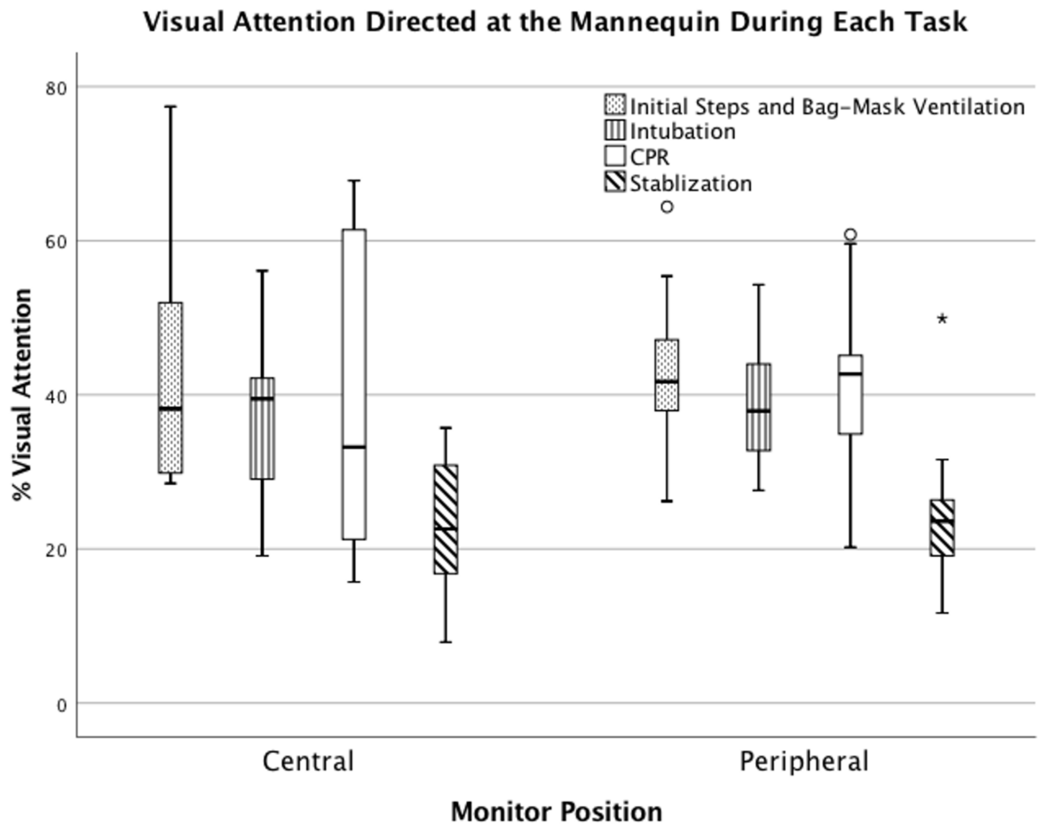


Figure 5.3 Visual Attention Directed at the Mannequin During Each Task.
Boxes extend from the 25th to the 75th percentile, horizontal bars represent the median, whiskers indicate the 5th and 95th percentiles, circles represent outliers > 1.5×IQR, and asterisk (*) represent extreme outliers > 3xIQR



Chapter 6. Analysis of Visual Attention and Team Communications during Neonatal Endotracheal Intubations using Eye-tracking

Brenda H. Law MD[1,2], Georg M. Schmölzer, MD PhD[1,2]

[1]Centre for the Studies of Asphyxia and Resuscitation, Royal Alexandra Hospital, Edmonton, Canada

[2]Department of Pediatrics, University of Alberta, Edmonton, Canada

6.1 Abstract

Background: Eye-tracking can be used to analyse visual attention (VA) of health care providers during clinical tasks. No study has examined eye-tracking during neonatal endotracheal intubation.

Objective: To use eye-tracking to examine VA and team communications during endotracheal intubation in the Neonatal Intensive Care Unit.

Methods: Twenty-seven video-recordings were obtained using eye-tracking glasses worn by intubators during endotracheal intubation of stable neonates. Videos were analyzed to obtain i) intubation duration and success, ii) areas of interest (AOIs), iii) duration spent on each AOI, iv) types and frequency of saccades between AOIs, and v) monitor looking behaviour, and vi) team communications of vital signs and verbal medication orders.

Results: Twenty-four videos were of acceptable quality and analysed. Median attempt duration was 44.7s. Success rate was 79%. Overall, 50% of VA was directed at the infant, with 23% of VA directed at equipment. There were 415 saccade types and 0.55 saccades/sec. Intubators glanced at the monitor spontaneously and rarely reported vital signs afterwards. Language used to communicate vital signs and medication orders varied.

Conclusion: During neonatal intubations, 50% of VA was directed away from the infant. Team communications were non-standard. Eye-tracking can be used to analyse human performance during neonatal resuscitation.

6.2 Introduction

Endotracheal intubation, a key procedure in the care of newborn infants, is routinely performed in the Neonatal Intensive Care Unit (NICU). Indications include mechanical ventilation, surfactant administration, or respiratory failure. While life-saving, unsuccessful or prolonged intubation attempts can result in acute complications such as bradycardia and hypoxia.[106,107] Multiple intubation attempts in the first four days post-birth have also been associated with severe intraventricular hemorrhage in preterm infants.[108] Further, traumatic intubations have been linked to long-term complications such as subglottic stenosis.[109]

With the increased use of non-invasive ventilation modalities, endotracheal intubations have become less frequent, thereby reducing opportunities for health care providers to develop and maintain competency.[110] Even amongst experienced clinicians, first intubation attempts are frequently unsuccessful, and adverse events are common.[107] While intubator experience and training play a role, other human factors such as teamwork and communication may also contribute to improving intubation success.

Mobile eye-tracking is a technology that measures and records visual attention (VA) in a dynamic environment.[18,19] Eye-tracking glasses use reflected infrared light to track pupillary movement and imaging processing to incorporate gaze patterns as markers into video from a participant's viewpoint. Previously, we studied VA in health care providers performing neonatal resuscitations.[47] Eye-tracking provides VA data, as well as video and audio recording of the environment from the perspective of the intubator. Researchers can therefore use eye-tracking to determine what areas in the clinical environment are of visual interest, the division and shifting of VA, as well as a video-audio record of the event for analysis of clinician performance, teamwork, and team communication.

In this pilot study, we aim to test the use of mobile eye-tracking glasses to study VA and team communication in non-urgent endotracheal intubations of stable neonates in the NICU.

6.3 Methods

This study was carried out from March 2018 to March 2019 at the NICU at the Royal Alexandra Hospital, Edmonton, Canada. The Royal Alexandra Hospital Research Committee and the Health Ethics Research Board, University of Alberta (Pro00077581) approved the study. Research team members, when available, were notified of plans for non-urgent endotracheal intubations in the NICU. Health care providers who are intubators (including neonatologists, neonatal fellows, pediatric residents, neonatal nurse practitioners, respiratory therapists, and neonatal transport nurses) were eligible to participate. Prior to the intubation, written informed consent was obtained. Health care providers other than the intubator were made aware of the recording and provided with an opportunity to opt out of the procedure. Exclusion criteria included urgent intubation or clinical instability (i.e., inadequate time to obtain consent from the intubator and to calibrate research equipment prior to intubation), or an intubator who declined to participate.

Each intubator was then fitted with mobile, head-mounted eye-tracking glasses (Tobii Glasses, Tobii Technology, Inc, Falls Church, Virginia, USA). Basic information about the infant (e.g., gestational age, current age, birth and current weight, Apgar score), information about the intubator (e.g., discipline, years of intubation experience), and procedure information (e.g., type of intubation, number of attempts and failures, premedication, type and size of endotracheal tube used, vital signs during intubation, complications) were recorded. No identifying information was collected from the infant.

Eye-tracking recordings of adequate quality (gaze capture >60%) were analyzed using a combination of manual analysis and Tobii Lab analyzer software (Tobii Technology, Inc, Falls Church, Virginia, USA) to assess VA. VA measures include: i) Areas of Interest (AOIs) (e.g. infant, vital signs monitor, laryngoscope, ventilation equipment); ii) cumulative time spent on each AOI, describing VA distribution; iii) saccade types (i.e., defined by origin and destination of saccades), iv) saccade frequency, a marker of cognitive loading and VA fragmentation; and iv) looks at the vital signs monitor. Monitor looks were individually analyzed to determine if the looks were immediately preceded by monitor alarms, team member actions, or were spontaneous, and what actions were taken after.

Transcripts of verbal team communication were made from the eye-tracking video recordings and analyzed for two key communications: i) verbalizations of vital signs displayed on the monitor (heart rate, oxygen saturation), and ii) verbal medication orders. Eye-tracking videos were also reviewed to determine i) telephone interruptions during the procedure, ii) presence of role confusion amongst the team members, iv) initial depth of endotracheal tube (ETT) placement, and iii) methods use to confirm ETT placement.

Statistical analysis was descriptive. The data are presented as mean (standard deviation (SD)) for normally distributed continuous variables and median (interquartile range (IQR)) when the distribution was skewed. Correlations were determined using Pearson product moment correlation. Statistical analyses were performed with SPSS 25 (IBM, Armonk, New York, USA).

6.4 Results

Twenty-seven intubation events were recorded. Of these, 24 recordings obtained from 17 intubators (neonatologist (n=1), neonatal fellows (n=3), pediatric resident (n=1), neonatal nurse practitioners (n=3), advance practice nurses (n=6), and respiratory therapists (n=3)) were of sufficient quality (gaze samples >60%) and analyzed. None of the participants felt that the eye-tracking glasses interfered with their intubation attempts. Intubations occurred at a median post-natal age of 12 (0-22) days, with 11 procedures occurring with 48 hours of birth (Table 6.1). Infants were 46% female, with a median (IQR) gestational age of GA 27 (25-28) weeks, and corrected gestational age of 28 (27-31) weeks. Infants had a birth weight of 943 (735-1180)g and actual weight of 975 (800-1410)g.

All infants were intubated orally; 15/24 were primary oral intubations with direct laryngoscopes, 2/24 were primary oral intubations with video laryngoscopes, 6/24 were tube exchanges with direct laryngoscopes, 1/24 was a minimally invasive surfactant treatment (MIST) with delivery of surfactant via an intravenous cannula introduced into the airway under direct laryngoscopy. In 23/24 recordings the participant successfully intubated the infant; in one recording, another intubator took over to complete the intubation. In total, there were 30 attempts, with 6 intubators making 2 attempts and 18 making one attempt.

Excluding the MIST procedure, 23/29 attempts were successful endotracheal intubations confirmed with the presence of expired CO_2; 13/23 of successful intubations had the endotracheal tube initially placed too deep (asymmetric breath sounds auscultated or deeper than intended depth). Mean duration of intubation attempts was 44.7 (28.3-57.8)sec. None of the infants developed bradycardia (heart rate <100/min), but desaturations were common; in seven (29%) events the infant maintained oxygen saturation >88%, and in 11 (46%) events oxygen saturation decreased to <70% (Table 6.1).

6.4.1 Visual Attention

Figure 6.1 shows still-frame examples of video VA data obtained from the eye-tracking glasses during an intubation. In total, AOIs were grouped into 32 unique types (Table 6.2). There was a median of 19 (17-21) AOI types per recording. VA complexity was further revealed in the saccade types; there were 415 unique saccade types identified in total (e.g., looking from the infant to the laryngoscope), with a median of 83 (62-99) saccade types per recording. Saccades were frequent, with a mean (SD) 0.55 (0.1) saccades per second, or a saccade once every 2 seconds (Table 6.3).

Visual attention was mostly directed to the infant, median 50 (39-61)%. Significant visual attention was also directed at medical equipment (23%), divided between intubation equipment (laryngoscope, endotracheal tube, suction, 7%), ventilation equipment (ventilator, CPAP machine, T-piece bag-mask device, 4%) and medication equipment (syringes, vials, intravenous lines, and medication pumps, 6%). The remaining visual attention was directed at team members (6%), monitors (5%), and in transition (10%) (Table 6.3).

Vital signs monitor looks were highly variable between recordings. There were a median of 16 (6-21) monitor looks per recording, and a median of 2 (IQR 1-3) monitor looks per minute. In total, 380 monitor looks were analyzed. Monitor looks were brief (median 1, 0.6-1.8sec). Most monitor looks (91%) were spontaneous (not precipitated by alarms or team member actions); 6% were prompted by new alarms, and 3% were prompted by team member actions or comments. While monitor looks were not significantly correlated with years of experience ($r=-0.21$, $p=0.35$), there was an unexpected positive correlation between lowest SpO_2 and monitor looks ($r=0.54$, $p=0.007$). A majority (91%) of monitor looks were followed by no immediate action; only 8% of monitor looks were followed by sharing of vital signs with the team or comments on the infant's clinical status.

6.4.2 Team Communication

Study of team communications was focused on two specific domains: i) communication of vital signs information, and ii) verbal medication ordering.

There was a median of 3.5 (2-6) vital sign verbalizations per recording. Of the 108 vital signs verbalizations, most (75%) were by team members other than the intubator. Most (72%) reported stable vitals signs. Most occurred during the intubation attempt (38%), or initiation of sedation and muscle relaxation (35%). Vital signs were reported in four distinct formats: i) reporting stability, 28% (e.g. "Heart rate's good, sats are good"); ii) expressing concern, 7% (e.g. "We've lost our sats"); iii) describing trends, 11% (e.g. "Sats are going down"), and iv) expressing numbers, 55% (e.g. "Heart rate is 170, sats are 100").

In our institution, standard weight-based emergency medication drug sheets were generated for each patient and kept at the bedside. Therefore, medication doses were not verbalized. Of the 64 verbal medication orders recorded, 55% were initiated by the intubator, 9% by a separate team leader, and 34% by the intubator or leader in response to a nurse question. Five procedures (21%) had repeated requests for the same medication. A minority (14%) of requests did not name a specific medication (e.g. "You can give the meds now").

Two separate medication administration strategies were observed: 1) administration of fentanyl followed immediately with succinylcholine, versus 2) slow administration of fentanyl. Both are strategies to avoid rigid chest syndrome as a side effect of fentanyl administration. This caused confusion in some nurses; in 4 recordings, the nurse needed clarification for this reason. Nurses were consistent in their reporting of medications given (92%). Medication orders came in six distinct formats (Table 6.4); only 15% were directive.

Finally, key information such as patient weight and anticipated endotracheal tube depth were rarely verbalized prior to the intubation attempt.

6.4.3 General Observations

Most intubations had five core team members: intubator, primary assisting respiratory therapist, nurse responsible for medication administration, nurse recorder, and second assisting respiratory therapist. The key role confusion identified was who would auscultate for breath sounds over the lung fields after intubation. This was a key task in confirming ETT placement, and was usually not explicitly assigned to a team member. Non-physician intubators (respiratory therapists, advance practice nurses, neonatal nurse practitioners) often perform tasks not crucial to the intubation procedure (e.g. programming pumps, setting up ventilator, checking medication vials), while physicians focused on the main intubation tasks. Eight procedures (33%) were interrupted by phone calls.

6.5 Discussion

To our knowledge, this is the first study to use mobile eye-tracking glasses to explore intubator VA and team behaviours during endotracheal intubations. Many previous eye-tracking studies were performed in simulation environments[95,111-113]; however, neonatal intubations can be difficult to simulate given the limitations of mannequins in replicating a challenging preterm airway.[14,15] In addition, VA may differ between simulated and actual clinical events.[102] In our study, we found that VA distribution differs from VA during neonatal resuscitations.[47] During neonatal resuscitations in the delivery room, VA was divided between the infant and vital signs monitors; in contrast, during intubations, 50% of VA was focused on the infant, while half of VA was directed away from the infant, mostly at equipment such as laryngoscopes, T-piece devices, and medication syringes. This highlights that intubation involves more than simple airway visualization. Saccades remain frequent and complex, with over 400 different saccade types identified. Minimal VA was focused on vital signs monitors, potentially as infants were stable at the beginning of the intubation events, compared with uncertainty at the start of neonatal resuscitation at birth.[47] Most monitor looks made by the intubator were spontaneous, and most intubators did not share any information with the team afterwards. Unexpectedly, monitor looks were also correlated with higher oxygen saturation rather than desaturations, further suggesting that frequent monitor checks were an inefficient method of situation monitoring.

Team communication of vital signs and verbal medication orders revealed barriers to effective communication. Verbal medication orders might be prone to misunderstanding and miscommunication[114], but are unavoidable in an intubation scenario. In a simulation study of emergency airway management by pediatric intensive care teams, Rozenfeld et al.[115] found that repeated medication requests were often needed, and that closed-loop communication of medication administration occurred only in 2/10 simulations. In contrast, in our study of controlled, non-emergent intubations, nurses almost universally reported medication administration completion. However, we found six distinct formats of verbal medication orders, some of which could be prone to misunderstanding. In particular, verbalization of readiness (e.g. "We're ready for the fentanyl") and permission (e.g. "You can give the fentanyl whenever you want") may not be understood as an order, and might be open to interpretation as to the intended timing for administration. Medication administration is a cooperative endeavor influenced by teamwork culture, and directive versus tentative medication ordering styles may be related to experience.[116]

When reported, vital signs were mainly verbalized by team members other than the intubator, demonstrating sharing of situation monitoring amongst the NICU intubation teams. We observed a disconnect between the frequency of monitor looks and the lack of verbalization of vitals signs; intubators frequent assessed vital signs but infrequently shared their findings with the team. Furthermore, the way vital signs were reported was non-standard and varied between individuals, with some reporting numbers, some reporting stability or concern, and others reporting trends. The use of non-standard communication has been associated with a trend towards increased human errors in simulated neonatal resuscitations[13]; standardization of vital signs communications during critical events such as endotracheal intubations might be an avenue for improving overall team communication.

Point of view video generated by mobile eye-tracking glasses also revealed several areas for potential quality improvement. Even with mostly experienced intubators under controlled settings, intubation attempts were longer than the recommended 30 seconds[4] and multiple attempts were sometimes needed. Phone calls were frequent and disruptive. Endotracheal tubes were frequently placed too deep with the stylet in-situ, potentially increasing the risk for airway trauma. Intubation checklists and pre-intubation time-outs have been shown to decrease adverse events such as hypoxemia and bradycardia in the NICU.[117] Eye-tracking could potentially be used to evaluate the difference in visual attention and team communication after an intubation checklist has been implemented.

This study had several limitations. The recorded intubations were of a specific type: none were emergent, and all were oral intubations performed on mostly extreme preterm infants. Participants were mostly experienced intubators; therefore, we could not compare the difference in visual attention between novices and experts. Visual attention is only one aspect of cognition and does not address the phenomenon of inattentional blindness, in which an individual may direct their gaze at an object and not comprehend its significance. Eye-tracking was also obtained from one institution, reflecting one institution's practice and experience; institutional differences such as the use of checklists and auditory alarms might change both intubator visual attention and team behaviours. While eye-tracking glasses did not interfere with the performance of this critical task, the complexity of the visual environment complicates data analysis automation, rendering data analysis labour intensive.

6.6 Conclusion

An intubator's visual attention during neonatal intubation is complex and involves more than airway visualization, with many areas of visual interest and frequent saccades. Variations in team communication of medication orders and vitals signs reveal opportunities for standardization to decrease risk for errors and misunderstanding. Eye-tracking can be used to study both individual performance and team behaviours during procedures such as neonatal intubation

6.7 Acknowledgements

We would like to thank Caroline Fray and Sylvia van Os for their assistance with data collection, and for Emily Zedner for assisting with VA data analysis.

Table 6.1 Participant, Infant, and Procedure Data

Participants	**Profession**	Neonatologist	1
		Neonatal Fellow	3
		Pediatric Resident	1
		Neonatal Nurse Practitioner	3
		Advance Practice Nurse	6
		Respiratory Therapist	3
	Years of experience (years)		10.5 (5-20)
Infants	**Sex n(%)**		Male 13(54)
			Female 11(46)
	Gestational age (weeks)#		27 (25-28)
	Corrected gestational age (weeks)#		28 (27-31)
	Birth weight (g)#		943 (725-1180)
	Weight at time of intubation (g)#		975 (800-1410)
	Post-natal age (days)#		12 (0-22)
Procedures	**Recording Duration (sec)#**		500 (365-601)
	Procedure Type	Total	24
		Oral Intubation with Direct Laryngoscopy	15
		Oral Tube Exchange with Direct Laryngoscopy	6
		Oral intubation with Video Laryngoscopy	2
		Minimally Invasive Surfactant Therapy	1
	Success rate		23/29 attempts
	Intubation attempt duration (sec)#		44.7 (28.3-57.8)
	Intubation events with desaturation below 88%		71%
	Intubation events with desaturation below 70%		46%

Data are presented as n(%), unless indicated median (IQR)#;

Table 6.2 Areas of Interest

Categories	Area of Interest
Infant	
Team Members	
Vital Signs Monitor	
Intubation Equipment	End Tidal CO2 detector Endotracheal Tube Laryngoscope Suction Video Laryngoscope Screen
Medication Related Equipment	Medications Vials and Syringes IV Lines Medication Pumps
Ventilation Equipment	CPAP Machine T-piece Resuscitator Pressure Gauges for T-piece Resuscitator Ventilator Ventilator / CPAP Circuit Oxygen Mixer
Other Equipment	Chart Clock Computer Screen Equipment Cart Gloves Nasal gastric tube and syringes Phone Stethoscope Transcutaneous CO2 monitor Infant Isolette / Warmer Miscellaneous Other Equipment
Intubator themselves	Intubator’s own hands Other
Other	Other People Room Infant Isolette / Warmer

Table 6.3 Summary of Visual Attention Results

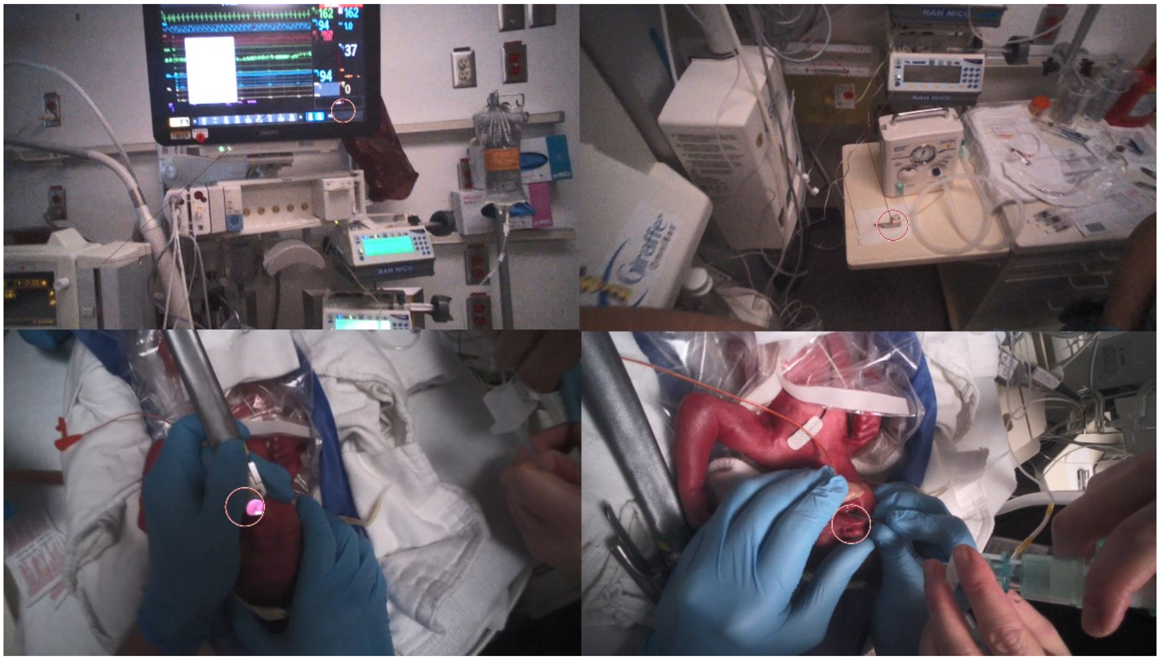
Areas of Interests observed during recording		19 (17-21)
Visual Attention Distribution	**Infant (%)**	50 (39-61)
	Team members (%)	6 (3-8)
	Equipment (Total) (%)	23 (20-32)
	Intubation equipment (%)[1]	7 (4-10)
	Ventilation equipment (%)[2]	4 (2-8)
	Medication equipment (%)[3]	6 (3-8)
	Other Equipment (%)	6 (3-8)
	Vital Signs Monitors (%)	5 (2-5)
	Transition (%)	10 (7-12)
Monitor Hits	**Total per recording**	16 (6-21)
	Frequency (looks per minute)	2 (1-3)
	Dwell time (duration of look) (sec)	1 (0.6-1.8)
Saccades	**Types**	83 (62-99)
	Frequency (saccades per second) [#]	0.55 (0.1)

Data are presented as median (IQR), unless indicated mean (SD)[#]; [1]Intubation equipment included laryngoscope, endotracheal tube, suction; [2]Ventilation equipment (ventilator, Continuous Positive Airway Pressures machine, circuits, T-piece resuscitator and mask); [3]Medication equipment included syringes, vials, intravenous lines, medication pumps.

Table 6.4 Verbal Communication Formats

	Format	Examples	Frequency
Vital Signs Verbalizations	Reporting Stability	"Heart rate's good, sats are good."	28%
	Expressing Concern	"We've lost our sats"	7%
	Describing Trends	"Sats are going down."	11%
	Expressing Numbers	"Heart rate is 170, sats are 100."	55%
Verbal Medications Ordering	1-2 Words	"Fentanyl." "Atropine now."	9%
	Affirmative response to nurse question.	Nurse: "Ready for the succ?" Intubator: "Go ahead"	31%
	Directive	"Give the atropine now."	16%
	Granting Permission	"You can give the atropine."	33%
	Verbalization of readiness.	"We're ready for the atropine."	6%
	Request / Question	"Can we give the fentanyl now?"	5%

Figure 6.1 Still-frame examples of eye-tracking video during an intubation demonstrating visual attention on 1) vital signs monitor screen 2) laryngoscope blade 3) airway of infant during laryngoscopy, and 3) Endotracheal Tube during final adjustment of Endotracheal Tube depth.*



* used with permission from the participant and from the infant’s family

Chapter 7. Discussion, Future Directions, and Conclusion

7.1 Discussion

In this thesis, I explored aspects of human factors and ergonomics as it pertains to neonatal resuscitation, using a combination of literature review, clinical observational studies, and simulation studies. While these studies were small, they demonstrated the potential applications of human factors principles to this area of health care.

Chapter 3 described one of the few randomized studies on equipment organization and human performance in neonatal resuscitation. Unlike previous studies, this study tested health care providers' ability to quickly and accurately access neonatal resuscitation equipment in a realistic simulation scenario. It demonstrated significant improvement in equipment access speed and overall scenario completion times using an ergonomic equipment box. This study is a proof of concept of how simple, low-cost improvements in physical ergonomics could potentially reduce time to interventions during neonatal resuscitation.

Several novel techniques for studying human factors and ergonomics in neonatal resuscitation were successfully implemented in these studies. First, mobile eye-tracking glasses were successful used to quantify visual attention in two distinct scenarios: neonatal resuscitation in the delivery room and endotracheal intubations in the NICU. This technique is acceptable to participants, quick to calibrate in the field, and did not interfere with the performance of clinical tasks. Several distinct metrics (AOI types, visual attention distribution, saccade types, and saccade frequency) could be elicited from eye-tracking recordings. Furthermore, visual attention can be related to other behaviors; in the study described in Chapter 6, we studied the relationship between monitor looks and vital signs reporting and concluded that, despite accessing vital signs information, intubators rarely shared that information verbally with their team members. Currently, eye-tracking in complex clinical environments is limited by the manual nature of data-analysis, as automated AOI detection performs poorly in this dynamic environment. Consequently, data analysis is labour intensive and relies in part on subjective AOI identification. Automation of AOI detection is being developed and may increase the applicability of this technology in the future.[118]

Second, a quantitative measure of situation awareness – Situation Awareness Global Assessment Tool – was tested in the simulation environment. This method has not been previously used in neonatal resuscitation, and, with some adaptations, SAGAT shows promise as a metric of situation awareness for future studies. More work is needed to develop better questions for higher levels of situation awareness, to determine inter-observer variability of this measure, and to compare with observational methods of quantifying SA. Furthermore, we could explore the use of SA questions in actual neonatal resuscitations, in which questions need to be concise to minimize disruption to clinical care.

Finally, Chapter 6 describes one of the few studies to examine verbal communication during intubation events in an intensive care unit. Patterns and variations in vital signs reporting and verbal medication orders were detected, highlighting the non-standard nature of team communication during a critical procedure (endotracheal intubation) in the NICU. Standardization of verbal communication during critical events such as neonatal resuscitations and endotracheal intubations could potentially reduce misunderstandings and miscommunications amongst team members.

7.2 Future Directions

To address the missing link between visual attention, perception, and cognition, further data can be elicited by using eye-tracking recordings as a prompt to debrief heath care providers after events such as delivery room resuscitations and endotracheal intubations in the NICU. Human factors techniques such as cognitive task analysis (CTA) can be used in conjunction with eye-tracking to elicit knowledge from experts.[119] Eye-tracking may also be used as a quality improvement and learning tool; eye-tracking has been used as a debriefing tool in simulation-based medical education[104] and may enhance learning gained from rare resuscitation events (e.g. resuscitation of rare anomalies such as congenital diaphragmatic hernia).

Further studies should be conducted to explore aspects of teamwork and team leadership during neonatal resuscitation. Currently, studies on teamwork in neonatal resuscitation have focused on team training and teamwork behaviors.[70,74,75] Both simulation and clinical studies can be used to compare different team leadership strategies, and how strategies such as a dedicated team leader or team coordinator may affect visual attention, situation awareness, and team behaviors during neonatal resuscitation and endotracheal intubations. Studies should also attempt to link human factors to neonatal outcomes; however, this is challenging due to the heterogeneous nature of the patient population, and the number of both patient and system factors that could potentially impact outcomes.

Finally, future research need not be limited to quantitative methods; qualitative methodologies may be better suited to study some psychosocial aspects of resuscitation performance, such as impact of interpersonal relationships, perception of hierarchy, conceptualizations of teamwork in the neonatal resuscitation environment.

7.3 Conclusion

Human factors and ergonomics principles, including physical, cognitive, and organization ergonomics, can be applied to study health care provider performance during neonatal resuscitation. Techniques such as mobile eye-tracking and Situation Awareness Global Assessment Tool can be used to study and compare aspects of human performance in both real life and simulation environments. More study is needed to better understand how human factors and ergonomics impact the effectiveness of neonatal resuscitation and neonatal outcomes.

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