Systematic Application of Human Factors and Ergonomics in the Neonatal ICU

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SAFETY BY DESIGN

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Patient safety in the Neonatal Intensive Care Unit (NICU) presents a formidable challenge due to the complexity of care provided, the reliance on technology, and the vulnerability of the patients, mainly preterm infants, who have very limited tolerance for error. As part of the Vermont Oxford Network’s Evidence-Based Quality Improvement Collaborative called Neonatal Intensive Care Quality (NIC/Q), a project was undertaken to improve patient safety by applying Human Factors science. Utilizing the findings of a web-based medical error reporting system, a series of self-assessment tools for NICU’s were created for and used by multi-disciplinary teams from 48 US and Canadian NICU’s. Each self-assessment tool was based on the Human Factors research literature; summarizing principles for evaluation and improvement of patient safety. These self-assessment tools consisted of checklists and evaluative tables to assess the design of the NICU work environment and operations. These tools have been proactively used for process improvement, hazard identification and control, unit design, selection and procurement of equipment, and procedure design. The tools also have supported response to occurrences through investigation analysis. The presentation will summarize the series content with examples of application and results.
1.0 Introduction

The Vermont Oxford Network (VON) is a non-profit voluntary collaboration of health care professionals dedicated to improving the quality and safety of medical care for newborn infants and their families. Established in 1988, the Network is today comprised of over 700 Neonatal Intensive Care Units around the world. NIC/Q is a series of multi-organization neonatal improvement collaboratives for VON members(1). NIC/Q has 3 primary goals:

- To achieve measurable improvements in the quality, safety and efficiency of NICU care.
- To develop new resources, tools and knowledge for quality improvement in the NICU.
- To disseminate this improvement knowledge to the neonatology community.

Neonatal Intensive Care Unit (NICU) care is complex, involving many systems and subsystems; the reliability of these systems is in part determined by natural limitations in human performance. The recognition of such limitations in general has directed extensive research and the formulation of human factors design specifications. The relevance of this field of study has been established through investigation of sentinel events in healthcare and experience in other high-risk activities.

The NICU Human Factors Checklist Series was developed to provide a means to guide changes based on human factors science and to educate NIC/Q participants on human factors; fostering a culture that focuses on system reliability. The approach taken with the Series was to engage front-line teams in review and evaluation of the system they work in in accordance with the concept of participatory ergonomics(2,3). The term “checklist” was applied in this instance to mean a self-assessment tool for the proactive evaluation of system characteristics and not, as is frequently used, a time-inspection tool to guide procedure following or real-time inspections of work factors.

The Human Factors Checklist Series goals are:

- deliver relevant human factors knowledge about how to prevent error to front-line clinicians,
- develop, test and refine methods for applying this knowledge,
- stimulate the collaborative exchange of experience with the application of this knowledge.

Where appropriate, the checklists followed a systematic framework (Figure 1) of five levels adapted from Moray(4). This approach to design and analysis progresses outward from the patient and enables consideration of human factors across system levels.

2.0 Methodology

2.1 The series approach

Each topic in the Series was presented in the context of error experience and current system characteristics of NICU care – equipment, environment, procedures, processes, materials and

![Figure 1](image)

**Figure 1**

<table>
<thead>
<tr>
<th>Organization and Management Factors</th>
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</thead>
<tbody>
<tr>
<td>Team and Group Factors</td>
</tr>
<tr>
<td>Individual Human Factors</td>
</tr>
<tr>
<td>Environment</td>
</tr>
<tr>
<td>Ergonomics</td>
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<tr>
<td>Point of Care</td>
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<td>design of equipment</td>
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<tr>
<td>physical surroundings</td>
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<tr>
<td>personal factors (e.g. fatigue)</td>
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<tr>
<td>team performance (e.g. communication)</td>
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<tr>
<td>Organizational policies and practices</td>
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</table>

people. Error experience was surveyed using a voluntary web-based error reporting system to which NIC/Q participants contributed.(5) Human Factors literature was reviewed and formed the basis for an educational session at one of the semi-annual NIC/Q meetings and a checklist to guide the application of principles and guidance summarized for each topic. Checklists were supplemented with worksheets adapted to guide self-assessment and the identification of potential changes to reduce error potential.

The scope of each topic was selected to enable progressive use of the series over time in a proactive manner. Teams also used the principles, checklists and tools to support the application of other safety tools such as Failure Modes and Effects Analysis and Root Cause Analysis.

2.2 Topics in the series

Checklist topics were identified based on the system of care, safety issues and reported error experience. The series of topics are summarized in Table 1. Further details for a sample of topics follows with cited principles and references:

Clinical Alarms - Alarming devices in the NICU with include: cardio-respiratory monitors, ventilators, pulse oximeters and IV pumps/syringes. Checklist topics include audibility, probability matching behavior, silencing and suspension behavior and controls (6-9).

Labels and Displays – Printed labels and visual displays often carry safety-critical information; in the NICU this includes medications, specimens and breast milk. Equipment associated with one patient’s bedside presents information in unique and occasionally conflicting ways. Checklist topics include visual characteristics, legibility, readability, redundancy, emphasis and salience. (10-14)

Alertness – The effects of fatigue on performance have been well established and the NICU is a 24/7 operation with some staff categories known to work 24 hour shifts. This checklist directs attention to the deployment of preventive countermeasures such as
shift design and rotation and operational countermeasures such as napping and light exposure. (15-19)

<table>
<thead>
<tr>
<th>Checklist Topic</th>
<th>NICU Examples</th>
<th>Key Human Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical Alarms</td>
<td>pulse oximeter, monitors, IV pumps, ventilators</td>
<td>parameter setting and response behavior</td>
</tr>
<tr>
<td>Labels and Displays</td>
<td>drugs, breast-milk, monitors</td>
<td>image characteristics, size, color</td>
</tr>
<tr>
<td>Procedure Following</td>
<td>daily care, line insertion and care</td>
<td>omission affordances, reminders, checklists</td>
</tr>
<tr>
<td>Device Usability</td>
<td>medical devices and equipment</td>
<td>usability heuristics and testing</td>
</tr>
<tr>
<td>Alertness</td>
<td>hours of work, fatigue effects</td>
<td>fatigue countermeasures, awareness</td>
</tr>
<tr>
<td>Warnings</td>
<td>signs, stickers, labels</td>
<td>design, placement, content</td>
</tr>
<tr>
<td>Paper Forms</td>
<td>orders, charts</td>
<td>process guide and communication</td>
</tr>
<tr>
<td>Team Performance</td>
<td>crisis response, OB perinatal</td>
<td>performance shaping factors, communication pattern</td>
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<tr>
<td>Unit Design</td>
<td>bedspace, headwalls, single patient rooms</td>
<td>process and proximity, communication</td>
</tr>
<tr>
<td>Physical Ergonomics</td>
<td>posture, layout, visual demand</td>
<td>adjustability, visibility, maintenance</td>
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Table 1. Topics in the Human Factors Checklist Series

Procedures and Task Guidance – Procedural controls are a prominent hazard control measure in the NICU - often relied upon exclusively. As with observations about human error generally (20, 21) incident review in the NICU identifies omission of procedural steps to be a common error type. This checklist directs attention to the review of omission affordances for specific errors and the use of reminders and checklists (22-24)

Device Usability - The provision of care in the NICU involves the use of medical devices that perform various functions critical to patient safety. Each unit has its own mix of devices which makes the context of use and review of equipment unique to each environment. This checklist uses a heuristic approach (25-28) to guide usability review or testing for devices that are in service or as a guide to support evaluation and safety considerations related to the procurement of new equipment.

2.3 Checklist application

Each checklist in the series was presented at one of the semiannual meetings of the NIC/Q project between September 2002 and October 2006. Following the meeting the checklist tool was posted on a private web site; the same site used for the anonymous error reporting system.

Following checklist introduction and education, it was recommended that checklists and associated analysis tools be used in a process of review undertaken by an interdisciplinary team. This team included people who work in the NICU and have the authority to make changes. In many cases conducting an assessment using one of the checklists involved a walk-through review and observation. The principles outlined under each topic and supplementary tools were also used without the checklist to support other analysis and investigation. For instance, the checklist on Device Usability was applied as part of evaluation and procurement on the occasion of acquiring new devices.

Advice about how to conduct self-assessment was provided and included:

- Planning for a 30 minute meeting immediately following the walk-through and observation to debrief assessment and findings.
- Identifying items from the checklist that will require action or further study.
- Assign responsibility for follow-through on these items.
- Identify standing committees or meetings that should be advised of the results of the assessment.

2.4 Scope and limitations

The checklist series and associated tools were used to guide review of human factors related to patient care systems in the NICU. These self-assessments were intended to identifying potential changes to improve patient safety. They were not intended to address all aspects of patient safety and the potential for medical error.

3.0 Results

Use of the checklist series by NIC/Q participants was accomplished using a formal reporting mechanism and through anecdotal reporting by participants. Formal reporting consisted of structured poster presentations at subsequent meetings. These poster sessions involved the presentation of safety improvements and an
invitation to share findings and application among NIC/Q participants. This resulted in potential spread of innovation and further collaborative learning about the relevance and application of human factors principles to improving the safety of NICU care.

The total number of safety case study posters presented at collaborative meetings is 223. Of these, 46 (20%) explicitly identified that the human factors checklist series was applied to improve safety. Examples include:

1) Improved response time and intervention to clinical alarms through process changes that addressed alarm limit and volume setting, discontinuation of alarms, monitor positioning, response performance expectation and minimized distraction.

2) Reduced skin breakdown and nasal septum erosion due to pressure from CPAP prongs using improved procedure following, restriction of product choice and reminders.

3) Improved utilization of procedural time-outs to verify patient, site, side etc. using effective reminders, clarified expectations for when to use time-outs, better workspace layout and standard documentation forms.

4) Using the Design Safety Concept Checklist as a guide, including the “point of Care” categories of ergonomics and environment, one team was able to create a new environment for delivering neonatal care to optimize ergonomics and safe patient care.

5) Checklists were used to conduct an investigation of emergency drug administration; the report cites that the human factors checklists formed a basis for multiple recommended changes.

Random safety audits have been deployed by many of the NICUs in the collaborative (29). An unanticipated benefit of the checklist series was the inclusion of human factors items in some unit’s random audit rotation. This enabled the ongoing monitoring of changes made as a result of using the checklists. For instance, alarm settings are included in one unit’s audit list. Another unit includes a review of IV line labels presence, visibility, legibility and use.

The process of methodically examining characteristics of the NICU system in a proactive manner using an interdisciplinary team approach created helpful side effects. Through the course using the checklist, teams uncovered issues outside the scope of the checklist in use, which were also important for patient care and safety. By working in a proactive manner there is less tension since the emotion of an adverse event does not distract the team’s resolve to examine system elements in a constructive manner.

When reviewing human factors elements of work systems it became apparent that processes such as equipment purchasing and maintenance and groups such as environmental services are involved in the system. They affect the system in a remote but important way. Instructions for use of the checklists suggested the involvement of others from outside the clinical team. For instance, the checklist self-assessment process raised the importance of procurement as an opportunity for the inclusion of criteria based on human factors science. Several units have reported the inclusion of these criteria and a formal human factors review for safety-critical equipment and devices.

Challenges to the inclusion of human factors knowledge gained through the use of the checklist include:

- recall of pertinent human factors principles
- involvement of new team members not familiar with the tool
- a lack of empirical evidence relating to the application of principles (will this really reduce errors?)

4.0 Conclusions

This series of learning modules provided a means to enhance the understanding of several human factors topics and their relevance to the NICU. This learning was supported through the application of checklists in an proactive manner that resulted in positive changes aimed at reducing errors and improving patient safety.

Clinical staff showed a keen interest in human factors science. Each subject provided them with an opportunity to look at the work environment, equipment, materials and task parameters in a new light. The fact that there is a scientific basis for the changes suggested by human factors principles is also well received and is congruent with the goal of evidence-based practice.

Education about human factors may also help to shift mental models concerned with how errors happen and what can do done to prevent them and control the associated hazards. The typical and oft-cited “shame and blame” approach may be more easily replaced when a positive and constructive alternative based on scientific research is available and used.

Since the series is now 6 years old, there is a need to revisit all the topics to update the literature review and augment the associated learning with rich examples from application in the NICU. Further development of safety improvement methods has been underway in the present iteration of the NIC/Q project. System safety and in particular preliminary hazard analysis has been introduced and an index of hazards is being developed. In the future this may be linked to the human factors principles through the deployment of web-based technology. Furthermore, there are now additional topics emerging and the the series topic list is likely to grow.

The Human Factors Checklist Series is a unique undertaking involving the review and specification of human factors principles relating to patient safety concerns in the NICU. The Series has led to the creation of a one-day course for all clinical specialties in a Toronto academic health center. This has demonstrated the general relevance of these topics across many different clinical areas. The course is a cornerstone for safety education and has been provided to over 350 staff to date.

Acknowledgments

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References


17. Dawson D, Campbell SS. Timed exposure to bright light improves sleep and alertness during simulated night shifts. Sleep 1991 14:5;11-6.


