A Human Factors Approach to Understanding and Designing for Infection Prevention and Control in a Neonatal Intensive Care Unit

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Abstract. Qualitative methods were used to understand infection prevention and control breaches within an existing neonatal intensive care unit and inform future design development. The study aimed to identify the main issues that health care workers experience in infection prevention and control and their relationship to the design of the environment. Methods from human-centred design such as planning, stakeholder meetings and naturalistic observation were used to document the unit, work processes, interactions, behaviours and perspectives of health care workers related to infection prevention and control. Thematic analysis was used to identify core issues, subthemes and their interrelationship to share with staff and inform recommendations.

Keywords. infection prevention and control, neonatal intensive care unit, human factors, design

1. Introduction

The Ontario Provincial Infectious Diseases Advisory Committee (Ontario PIDAC, 2012) defines an infection as "the entry and multiplication of an infectious agent in the tissues of the host" (p. xii). It can be asymptomatic or symptomatic, and is caused by a microorganism such as a bacterium, fungus, parasite, virus or prion. The report further comments that, as health care workers (HCWs) move through their workplaces, they circulate between patients and equipment, carrying out tasks that provide opportunities to transmit microorganisms carried on their hands and increasing the risk of hospital acquired infections (HAIs). Newborns are particularly vulnerable to HAIs due to inherent risk factors such as low birth weight, underlying illness, immature immune systems and greater skin permeability. It also recommends that, whereas general practice requires the 'four moments' of hand hygiene to break the chain of transmission, neonatal intensive care (NICU) and infection prevention and control (IPAC) guidelines recommend 'five moments' of hand hygiene adding an additional hand hygiene step, or barrier to transmission, prior to entering the neonate environment (i.e. the bed/isolette/warmer)(ibid).

Despite considerable research in IPAC, with over 2500 hand hygiene related studies alone published on PubMed since 1995, few studies mention human factors or ergonomics. Ulrich & Zimring (2004) identified a need for more research in environment design and infection prevention from a HF/E perspective in order to develop a better understanding of the influence of design on best practice in IPAC.

Ten years later, a title/abstract search on PubMed (February 4th, 2015) illustrates the limited role and recognition of HF/E within IPAC, with only a handful of references to human factors (two results) or ergonomics (eight results) in IPAC research.

According to Sax et al. (2009) ideal methods for studying infection prevention measures, such as hand hygiene, should be: free from the effects of observer bias; not interfere with end-user behaviour; capture every hand hygiene moment or lack thereof; produce a microbiological result of each hand hygiene action in real time; and not depend on extensive human or financial resources to study. However, even if such a method existed, the reality of many health care environments is that they demonstrate a high level of complexity which may not be conducive to such controlled, engineered approaches (Perry, Wears & Fairbanks, 2012).

Understanding IPAC concerns within a specific context, such as a NICU, and developing recommendations for further design study therefore requires exploring the issues that front-line staff are experiencing within the complexities of their environment (Guest, MacQueen, Namey, 2012). This can be supported by a method of analysis that moves beyond simply describing end-users, their tasks, environment and interactions to identifying patterns of behaviour that are preoccupied with achieving a goal or resolving a concern (Breckenridge, 2012). Methods drawn from human centered design (HCD) were used to learn as much as possible about users, their tasks and their work environment prior to the design process. This in-depth learning would help ensure that recommendations for improvement remain grounded in supporting the issues HCWs are trying to solve (Rogers, Sharp & Preece, 2012).

Thematic analysis helped move the study beyond describing individual experiences (Guest et al., 2012) documented during naturalistic observation to theorizing why certain behaviours were prevalent and what may be influencing them. The framework that was developed from the analysis reflected a systemic approach to understanding concerns around IPAC by illustrating interactions among various themes: from the physical and cognitive aspects of design; to the design of work; and to the influence of work motivations on best practice in infection prevention.

2. Methods

Participants: The study took place in a NICU designed in 1995, primarily at the patient bedside. Observations and/or feedback from 81 health care workers between 25 and 65 years of age (e.g. nurses, respiratory therapists, student nurses, housekeepers, staff physicians, ultrasound technicians) were documented using field notes, photos and sketches. Ethics approval was obtained from the hospital and the University of Nottingham.

Early inquiry methods from HCD frameworks including planning, stakeholder meetings and naturalistic observation (Maguire, 2001) were used to gain a deeper understanding of the participants' context, tasks, and goals (Rogers et al., 2012) in relation to IPAC. Six planning and feedback meetings were held with stakeholders and information was transcribed from field notes and reviewed as part of the thematic analysis. Naturalistic observation included opportunities for informal feedback from HCWs so they could explain what they do or how they complete a task. Fifty hours of observations were conducted by the researcher over the course of twelve shifts on weekdays and weekends. Observations took place over four hours, equally distributed over the twelve hour day and night shifts covering the beginning, middle and end of shifts. The majority of observed bedside care tasks consisted of routine care, followed by less frequent tasks including bloodwork, total parenteral nutrition (TPN) set up, tracheal intubation and a lumbar puncture procedure. Other tasks such as housekeeping, supply stocking and

rounds were also documented. Aside from question guides and field note templates, the researcher used a sketch pad, digital camera and measuring tape to document observations.

Thematic analysis was used to synthesize data and was conducted iteratively and concurrently throughout the meeting and observation sessions. This involved the researcher familiarizing herself with the data; developing codes and counting the instance of codes; searching for themes among codes; reviewing, naming and refining the themes, all of which culminated in a final framework of findings (Braun & Clarke, 2006). The researcher transcribed hand written field notes to a digital document following meeting and observations sessions, coded the data concurrently using process codes or 'gerunds' and wrote memos concurrently to inform and focus subsequent observation strategies and develop questions to clarify observations (Charmaz, 2014; Saldaña, 2009). The thematic framework served as an organizing principle for illustrating the interpretation of the data and "facilitating disclosure for the researcher and understanding for the reader" (Attride-Stirling, 2001, p. 387-390). A feedback meeting with participants on the preliminary thematic analysis supported with sketches of possible improvement strategies were used to confirm whether findings resonated with their understanding of issues and findings from this meeting were used to refine the thematic framework.

3. Results

The documentation and coding of data from the planning stage, observations and feedback meeting on preliminary findings from thematic analysis consisted of c.5000 words of stakeholder meeting notes and codes, c.46,000 words of observation documentation and codes and c.3000 words of researcher memos. The analysis of codes and categories of codes led to the development of key subthemes that helped facilitate a better understanding of breaches in infection prevention:

- high-touch items may be covertly compromising the maintenance of transmission barriers between the patient/hospital environment and between infant bays;
- HCWs experience physical and cognitive exertion to adapt to and manage spatial limitations within the environment which may be compromising infection practice;
- nurses' job descriptions have expanded to manage the environment and uphold barriers to transmission (e.g. increased cleaning and disinfecting protocols);
- nurses' need to feel prepared and complete tasks in a timely manner may take priority over good IPAC practice, suggesting better supports and processes are required to reduce, simplify and/or slow down steps in their work process to fulfill this need and facilitate safer behaviour;
- mental models of IPAC, specifically understanding the differences between the patient and hospital environment, and clean versus soiled items, may be influencing practice.

The predominance of these themes were also compared to the occurrence of words in the codes. The words which occurred most frequently in describing tasks associated with infection prevention practice included equipment, furniture, supplies, drawers, bedside counter, isolette, chart, and waste. Although such instance counts do not provide insight into why the words recurred, they perhaps indicate aspects worthy of further design study.

The core finding from the study showed that some staff engaged knowingly and unknowingly in unsafe IPAC behaviour while completing bedside care tasks while other staff expended a great deal of effort to maintain safe practice in infection prevention. Whereas some staff engaged in a great number of steps to maintain a safe line, distinction or space between the hospital and the patient environment by wiping down surfaces with germicidal wipes, performing hand hygiene at the right time or performing hand hygiene more than required; other staff neglected or unknowingly engaged in risky behaviour in completing tasks. Such variations in practice suggest HCWs have different understandings or 'mental models' of IPAC, and that faulty or incomplete models may be undermining best practice. The study showed that such compromised models of IPAC may be influenced by a lack of design affordances and environmental supports to help clarify transmission risks, better facilitate work objectives and support safer behaviour.

Observations and feedback revealed, for example, that complex tasks requiring hand hygiene are not supported by design. Despite being fully aware of the "five moments of hand hygiene" prescribed for NICUs, HCWs could not adopt the practice because the neonate environment (i.e. isolettes, warmers, cots) were not designed to hold alcohol-based hand rub (ABHR). Observations showed hand hygiene was also complicated by managing equipment alarms and supplies outside the neonate environment. Alarms go off frequently and in the event that staff are required to leave the neonate environment to silence an alarm, ABHR is not available at the point of interaction (i.e. the bed) and must be accessed at the work counter, which is not within arm's reach. Further, alarms may go off while HCWs' hands are occupied holding supplies or the infant within the bed area, which requires them to use one hand to silence the alarms while using the other hand to maintain their hold or position on the task they are performing. HCWs' hands may also be occupied (e.g. holding an infant) while reaching with the other hand for supplies. Thus, even if ABHR were available at the point of care, performing hand hygiene may be difficult since two handed rubbing action is required. For this reason, HCWs try to keep supplies close to the bed area, an activity that is not well supported by current bed equipment designs.

The study also showed that the good intentions of HCWs in providing patient care may be compromising IPAC. Some HCWs expressed that they felt pressed for time in their work and shared concerns around breaching when faced with a patient's deteriorating condition. Under such conditions, HCWs may resist a functional mental model of IPAC that requires more time or steps to achieve in favour of a faulty thought process that allows them to work more quickly.

4. Discussion and Conclusion

Various themes resulted from this study. One theme emerged as the most important: the design of products and the environment is undermining HCWs' understanding and practice of IPAC and contributing to variations in practice. Variations and breaches in IPAC are being fueled by an absence of design affordances and environmental supports, qualities which may help clarify transmission risks, better facilitate work objectives and support safer behaviour. Two products were developed from the analysis: a 'Framework of Findings - NICU IPAC Study' illustrating the core theme and subthemes (see Figure 1); and the 'NICU IPAC Design Exploration Guide - Detailed Findings and Recommendations', which details specific issues that may help inform future research and design development (discussed elsewhere). The human factors contribution of this framework is that it illustrates the interrelationship of these themes within the work processes of HCWs.

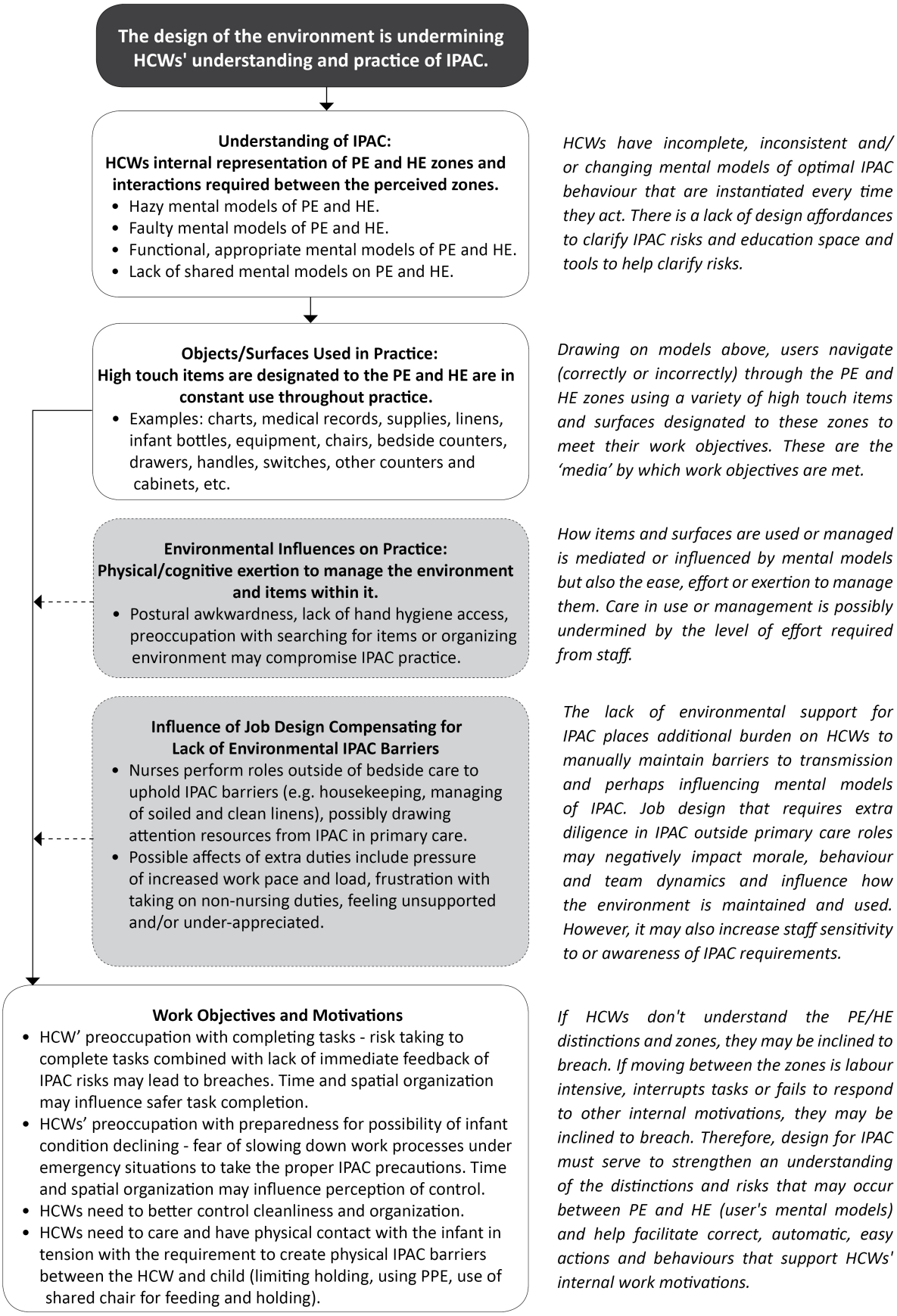

Figure 1: Framework of Findings - NICU IPAC Study

The findings revealed that HCWs have different 'mental models' of IPAC and faulty or incomplete models may be undermining best practice. This is supported by previous work from Pessoa-Silva et al. (2007) and Sax & Clack (2015) who suggested individual characteristics and varying mental models may play a role in IPAC. The study showed that such differences are influenced by a lack of design affordances and environmental supports that could help clarify transmission risks or help HCWs meet their work objectives more easily and safely.

Future research opportunities include developing further insight on the framework and testing recommendations for improvement using methods from ensuing phases of human-centred design and statistical analysis. This phase of research could help refine our understanding of the NICU requirements with the objective of developing designs that are desirable, feasible and sensitive to the complexities posed by IPAC.

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