This is an Accepted Manuscript of an article published by Taylor & Francis in Ergonomics on 09.05.2017, available online: http://www.tandfonline.com/ 10.1080/00140139.2017.1330967

Human factors considerations in designing for infection prevention and control in neonatal care – findings from a pre-design inquiry

Trudel, Chantal[a,b,*], Cobb, Sue[a], Momtahan, Kathryn[c], Brintnell, Janet[d] and Mitchell, Ann[d]

[a]*Faculty of Engineering, Human Factors Research Group, University of Nottingham, UK*
[b]*School of Industrial Design, Carleton University, Ontario, Canada*
[c]*Ottawa Hospital Research Institute, Ontario, Canada*
[d]*The Ottawa Hospital, Ontario, Canada*
[*] Corresponding author. Email: chantal.trudel@carleton.ca

Abstract

Qualitative data collection methods drawn from the early stages of human-centred design frameworks combined with thematic analysis were used to develop an understanding of infection prevention practice within an existing neonatal intensive care unit. Findings were used to generate a framework of understanding which in turn helped inform a baseline approach for future research and design development. The study revealed that a lack of clarity between infection transmission zones and a lack of design attributes needed to uphold infection prevention measures may be undermining healthcare workers' understanding and application of good practice. The issue may be further complicated by well-intentioned behavioural attitudes to meeting work objectives; undue influences from spatial constraints; the influence of inadvertent and excessive touch-based interactions; physical and/or cognitive exertion to maintain transmission barriers; and the impact of expanding job design and increased workload to supplement for lack of effective barriers.

Practitioner Summary: Despite high hand hygiene compliance within a neonatal intensive care unit, healthcare workers expressed concerns about the unit design and infection prevention practice. Early inquiry methods from human-centred design and thematic analysis helped develop a framework to understand how design can be used to aid infection prevention.

Keywords

Infection prevention and control, neonatal intensive care unit, human factors, ergonomics design

1. Introduction

This article is an extension of a paper entitled 'A Human Factors Approach to Understanding and Designing for Infection Prevention and Control in a Neonatal Intensive Care Unit' (Trudel et al. 2016) presented at Ergonomics and Human Factors 2016, 19–21 April 2016. This paper includes an extended review of literature and provides additional information on the methods used in the study, as well as a more comprehensive presentation of results and a revised thematic framework.

1.1. Background on healthcare-associated infections in neonates and routine practice in infection prevention

Healthcare-associated infections (HAIs) are acquired during the delivery of health care and can result from exposure to invasive devices, exposure to broad-spectrum antibiotics, interactions within the health care environment, over-crowding and poor staffing ratios (Ontario Agency for Health Protection and Promotion (Public Health Ontario), Provincial Infectious Diseases Advisory Committee (PIDAC) 2012a; 2012b). Healthcare involves frequent circulation between patients, equipment, furniture and the environment. This activity creates opportunities to transmit micro-organisms carried on the hands of healthcare workers (HCWs) increasing the risk of HAIs. Newborns hospitalised in neonatal intensive care units are particularly vulnerable to HAIs because of inherent risk factors such as low birth weight, underlying illness, undeveloped immune systems and greater skin permeability (2012a).

The Public Health Agency of Canada (2012) and Public Health Ontario (2012a , 2012b) outline two core processes in infection prevention: *routine practice*, a fundamental requirement used on 'all patients at all times in all healthcare settings' (Canada, Public Health Agency of Canada 2012, 7); and *additional precautions*, a more rigorous process used when risk assessments performed on a patient suggest extra barriers are required to mitigate the risk of infection transmission. Whereas routine practice requires the 'four moments' of hand hygiene (Figure 1) to break the chain of transmission, guidelines for neonatal care recommend 'five moments' of hand hygiene (Figure 2) adding an additional hand hygiene step, or barrier to transmission, prior to entering the neonate environment (i.e. the bed area). Yet despite such guidelines and the introduction of new technologies which are helping improve survival rates and outcomes for neonates, 'infectious complications are still a paradigm to defeat' (Pessoa-Silva et al. 2007, e389).

Figure 1. Decisions regarding IPAC can be discussed in terms of Routine Practice and Additional Precautions. The 4 moments of hand hygiene are required on all patients at all times in routine practice. Adapted with the permission of Public Health Ontario (Ontario, Public Health Ontario 2015).

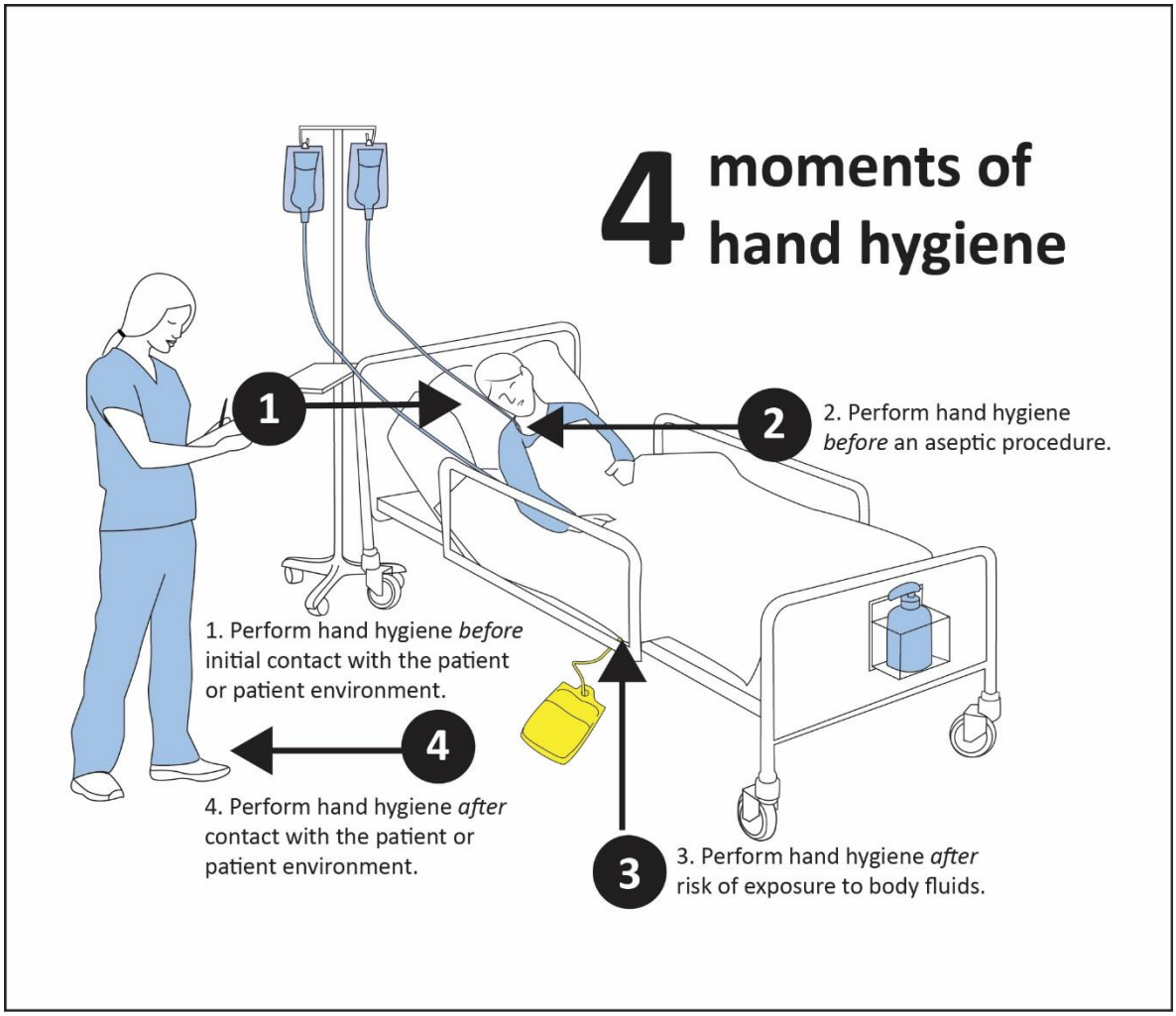


Figure 2. Neonatal intensive care requires '5 moments' of hand hygiene. Apart from the requirements outlined in the '4 moments', an additional hand hygiene step is required prior to entering the neonate environment (Ontario Agency for Health Protection and Promotion (Public Health Ontario), Provincial Infectious Diseases Advisory Committee (PIDAC) 2012a). This graphic illustrates this additional moment but also illustrates that as healthcare workers cross from one zone to another, hand hygiene is required.

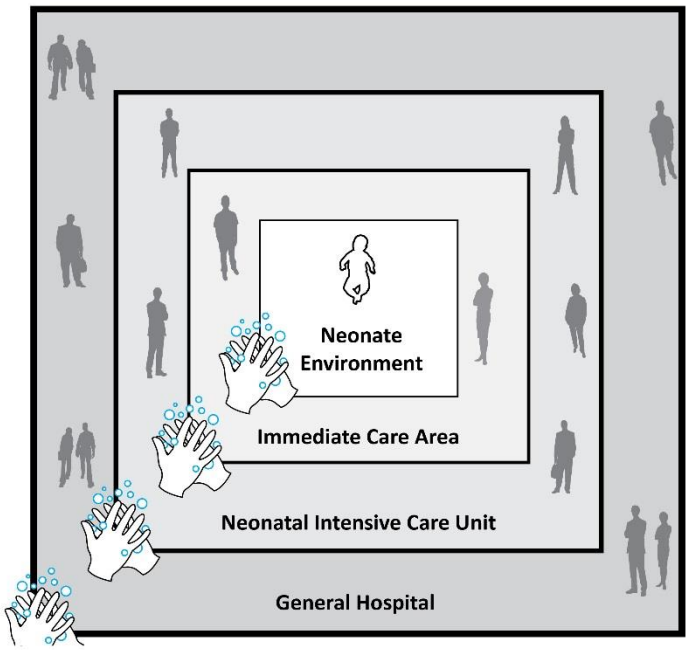
Neonatal Intensive Care Unit (NICU) Hand Hygiene Moments within the Larger System

General Hospital Environment:
Clean hands on each entry to the general health care facility.

Neonatal Intensive Care Unit Environment:
Clean hands on initial entry to the NICU.

Immediate Care Environment: Clean hands upon each entry into the immediate care area and upon leaving the space (e.g. patient room, infant bay).

Neonate Environment:
Clean hands upon each entry to the space.



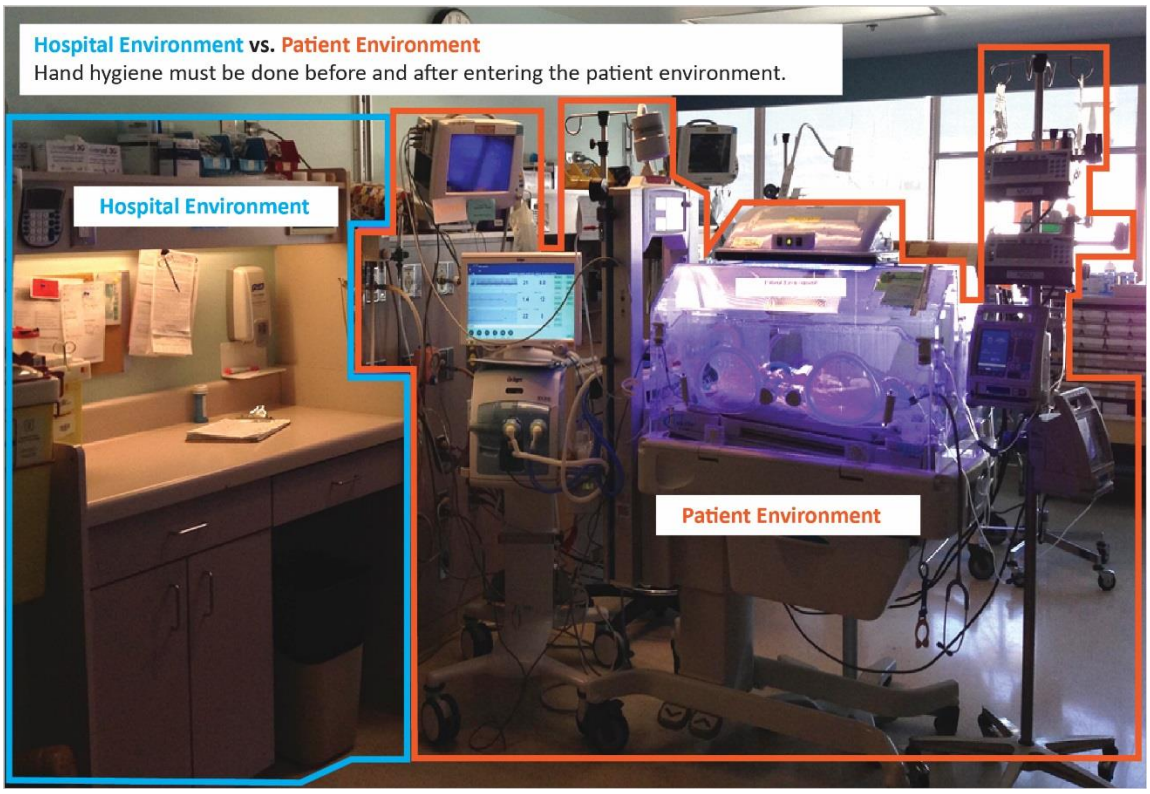
General Hand Hygiene Moments	Hand Hygiene Moments Prescribed for NICUs
Four moments of hand hygiene performed:	**Five moments of hand hygiene performed:**
1. before initial contact with patient or environment	1. before initial contact with patient or environment
	1a. before each entry into the infant isolette/warmer that holds the neonate
2. before performing aseptic procedure	2. before performing aseptic procedure
3. after care involving bodily fluid	3. after care involving bodily fluid
4. after contact with patient or their environment	4. after contact with patient or their environment

1.2. The existing context and the need for empirical inquiry

The subject of this study, a Level III Neonatal Intensive Care Unit (NICU) ward was renovated prior to design standards introduced by White in 2006. The existing environment lacks single patient rooms, recommended space per infant and dedicated hand-wash sinks for each patient (White 2006, 2007). Despite audit reports of high hand hygiene compliance during the time of the study (approximately 90%), HCWs were still concerned with supporting best practice in infection prevention specifically for transmission risks such as group B streptococcus and *Staphylococcus aureus*. The unit was investigating the use of invasive devices and broad spectrum antibiotics to mitigate transmission risks, but were also interested in studying the influence of interactions with the product and environment design on infection prevention practice.

In early discussions, HCWs explained their inability to implement the 'five moments' of hand hygiene prescribed for NICUs (Figure 2) due to its incompatibility with work processes and the design of the unit. In response, they adopted the 'four moments' model (Figure 1) zoning the unit as hospital environment (HE) or patient environment (PE) to help uphold barriers to pathogen transmission (Figure 3). Staff were instructed to perform hand hygiene prior to entering and touching items as they crossed these zones and disinfecting or discarding items that crossed zones. HCWs felt that workflow from one bedside work station to another, the use of shared equipment as well as supply practices at the beside were their main challenges in infection prevention and control (IPAC or IPC) and that the existing design was making it easier for people to breach. HCWs were particularly concerned about the design of supply management, noting supplies might become contaminated by staff who had prior contact with the HE without performing hand hygiene, or conversely, contact with the PE prior to touching supplies located in the HE without performing hand hygiene. Without a more thorough understanding of the infection prevention experiences of front-line staff, it was not clear that the issues discussed here represented a comprehensive understanding of the challenges in IPAC, and stakeholders were interested in a more thorough investigation to help inform future design development.

Figure 3. Zoning diagram developed by the NICU to help healthcare workers distinguish between the patient environment (PE) and the hospital environment (HE) in order to perform hand hygiene and disinfect items used between zones.



Ulrich et al. (2004) consider the neglect of human factors knowledge and research methods in IPAC studies to be a weakness in the literature. Inquiry from a human factors perspective incorporates the 'bottom up perspective' of front-line staff, the 'top-down interests' of administration or indirect stakeholders and focuses on developing recommendations that minimise the effects of existing constraints, complement the strengths and abilities of end-users, and avoids forcing them to adapt to undesirable work conditions (Institute of Ergonomics and Human Factors 2015).

1.3. Themes in infection prevention and control related to design

The difficulties in supporting good practice in infection prevention and control have been related to a variety of themes such as:

- poorly designed, located or insufficient quantities of hand hygiene equipment; and lack of alcohol-based hand rub (ABHR) at the point-of-care (e.g. Graham 1990; Muto, Sistrom, and Farr 2000; Pittet 2000; Chagpar et al. 2010);
- skin irritation from hand hygiene (e.g. Kampf and Löffler 2003; Luk et al. 2011);
- glove discomfort or perception that glove use replaces hand hygiene (e.g. Thompson et al. 1997);
- the prevalence of high-touch surfaces which may harbour pathogens in proximity to patients and staff (e.g. Huslage et al. 2010);
- crowded conditions which bring staff and patients in closer proximity to high-touch surfaces or make working conditions difficult to navigate (e.g. Archibald et al. 1997);
- the use of ward style/semi-private rooms which can contribute to crowding and cross-contamination versus the recommended use of single rooms (e.g. Goldmann, Durbin, & Freeman 1981);
- poorly located supplies or disconnects between physical layout and work processes (e.g. Hendrich 2003; Ulrich et al. 2004);
- time constraints, pace of work, high workload and understaffing (e.g. Archibald et al. 1997; Pittet 2001; Ulrich et al. 2004);
- perception that the risk of acquiring or transmitting infections is low (e.g. Pittet 2001; Bryant, McLaughlin, and Walsh 2012);
- perception that IPAC interferes with staff-patient relations or that patient needs are a priority over hand hygiene (e.g. Pittet 2001);

- lack of knowledge or disagreement with IPAC guidelines (e.g. Pittet 2001);
- flawed or incomplete understandings or 'mental models' of IPAC (e.g. Sax and Clack 2015)

These themes may be difficult to examine in isolation. For example, even if the space and quantity of supplies, equipment or hand hygiene stations are appropriate, the physical layout of these items may not be aligned with work processes (Ulrich et al. 2004). ABHR, for example, should be available at the point-of-care to facilitate hand hygiene at the right time (Pittet 2000) although Pessoa-Silva et al. (2007) note that optimal timing of hand cleansing in neonatal care has not been defined. Proximity to the point-of-care or at logical transitions between PE and HE does not necessarily increase the use of hand hygiene products. Haas and Larson (2008) reported wearable ABHRs, which by virtue of being located on staff are always located at the point-of-care, were only used for 9% of hand hygiene moments. Similarly, Muto, Sistrom, and Farr (2000) found placing alcohol-gel dispensers next to patient room doors did not increase hand hygiene.

Pessoa-Silva et al. (2007) observed that hand hygiene practice varies among HCWs working within the same contexts, suggesting that individual characteristics may play an important part in understanding behavioural considerations in IPAC. Sax and Clack (2015) suggest HCWs have no means of clearly associating their behaviour (e.g. failing to perform hand hygiene) with delayed, adverse events (e.g. a child acquiring an infection) and that this may be undermining their awareness or appreciation for the infectious risks associated with their behaviour. This phenomenon may be undermining their understanding of or appreciation for IPAC, resulting in a flawed or incomplete mental model of rules and outcomes associated with infection prevention. Since pathogens are not visible to the human eye (except when hands are visibly soiled), simple, unambiguous rules, cues or affordances become important to promoting infection prevention measures and discouraging unsafe behaviour (Pessoa-Silva et al. 2007; Sax and Clack 2015). Chagpar et al. (2010) recommend basic heuristics such as locating ABHR within arm's reach of patient room doors, using distinctive looking products for different dispensers, and mounting glove boxes to increase visibility and access. However, they note that planning is 'highly context dependent' and should engage front-line users to determine optimal conditions (Chagpar et al. 2010, 65). The themes discussed here are far from complete yet illustrate how issues belong to various domains (e.g. design of the environment/products, work processes, workload, education, behavioural and cognitive considerations, etc.) which may add to the complexity in designing for infection prevention.

2. Objective and rationale for study design

2.1. Human factors perspective in infection prevention and control research

To address such complexities, some researchers advocate for multimodal, multidisciplinary and systemic methods (see Pittet 2001; Pessoa-Silva et al. 2007; Alvarado 2012), to support a 'work system approach' to infection prevention where factors are evaluated within the larger system. Patient ceiling lifts, for example, have been widely implemented to reduce manual handling injuries but may inadvertently increase the risk of infection transmission between patients if they are difficult to clean between patient use (Alvarado 2012). A human factors approach may help foster a systemic approach by identifying considerations that fall outside the traditional design domains (e.g. the impact of job design, workload, education or training) or influences outside a particular field of design (e.g. the relative impacts of or interactions between product, graphic, architectural and/or digital design).

2.2. The value of using multiple, human-centred design methods early in design

Friedman (2003) notes that designers, in general, are taking on increasingly important and complex tasks and suggests 'lack of method and absence of systematic and comprehensive understanding' (509) in design development may have far reaching effects. In discussing architectural design, Remijn (2006) argues that a bottom-up or front-line approach to inquiry will help designers better understand the design challenge since 'in such a complex work situation it is plausible that practice differs from the expected situation by architect and perception of management' and 'this can result in a layout that does not fit the future operating process and task demands' (2).

Human-centred design frameworks (see, e.g. International Organization for Standardization or ISO 9241–210:2010 [2015] & Maguire [2001] further information) offer inquiry techniques that can be used early in, or prior to, the design process to foster a greater understanding of the end-users' context, tasks and goals. This is an important objective in the investigation of complex work like health care, since it may be difficult for people to describe what they do (Rogers, Sharp, and Preece 2012). Stakeholder meetings and naturalistic observation are well suited to the constraints of busy and critical clinical work environments. Such activities facilitate the collection of detailed user, process and contextual information within the natural setting, encouraging end-users to comment freely during meetings and observations.

Thematic analysis helps move an analysis beyond merely describing individual experiences (Guest, MacQueen, and Namey 2012) to theorising why certain behaviours are prevalent and what may be influencing them (Braun and Clarke 2006). Among the various coding techniques, coding for action or in 'gerunds' keeps the codes tied to activities and reduces the tendency 'to make conceptual leaps and adopt extant theories' before doing the necessary analytic work (Charmaz 2014, 116–117). This approach helps support the validity of the interpretation since codes are tied to participant activities and

statements (Saldaña 2009). The thematic framework presents the interpretation of the data, 'facilitating disclosure for the researcher and understanding for the reader' (Attride-Stirling 2001, 387–390) important to informing recommendations for future research and design development.

Our study focused on developing an understanding of the systemic factors related to design that may be contributing to breaches. By collecting data on the context and activities of front-line staff through stakeholder meetings and naturalistic observation combined with a concurrent process of thematic analysis, we were able to generate a framework illustrating the issues staff are experiencing and inform recommendations for future study and/or design development.

3. Methods

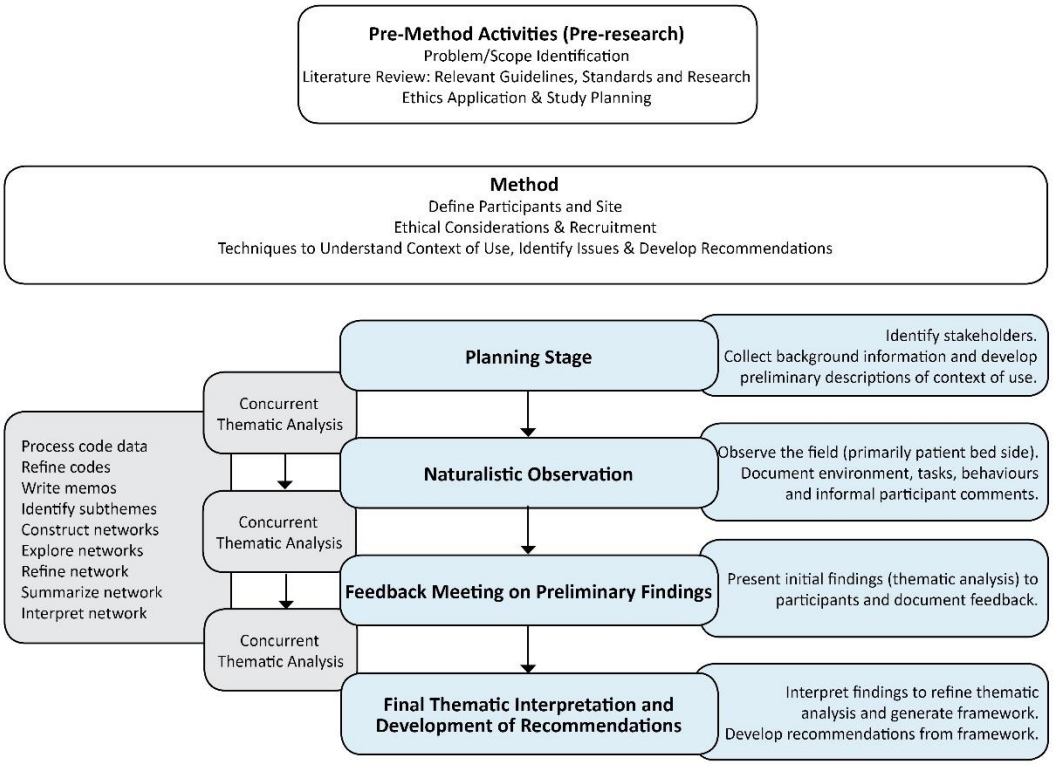
3.1. Participants

Participants ranged between 25 and 65 years of age and consisted of 81 HCWs (nurses, respiratory therapists, housekeepers, medical residents, nurse educators, supply logistic workers, physicians, care facilitators, ultrasound and X-ray technicians, student nurses and respiratory therapists) with the majority consisting of nurses. Staff were de-identified and informed that, whenever a breach or suspected breach was observed, the researcher would discuss the event with them afterward in order to gain more insight on the phenomena. The study obtained ethics approval from the hospital and the University of Nottingham.

3.2. Understanding the context, identifying issues & developing recommendations

The study (Figure 4) consisted of data collection methods drawn from the early stages of human-centred design and a concurrent process of thematic analysis to synthesise the data into a final framework of understanding.

Figure 4. NICU IPAC study design



3.2.1. Planning stage

Planning involved identifying stakeholders and the objectives of the unit; defining the research question and scope; documenting the existing design and first impressions; becoming familiar with routine care and hand hygiene protocols; documenting bedside supply use; and developing strategies to suit work processes and the study time frame. Although the researcher had no formal training in observing hand hygiene moments, a review of hand hygiene literature was conducted and a nurse educator experienced in audits, provided the researcher with a training session to sensitise her to the unit's practice.

3.2.2. Naturalistic observation

Fifty hours of observations were conducted in twelve 4-h intervals covering the complete 24 h work cycle on weekdays and weekends. Two observations extended to 5-h to observe specific processes (e.g. blood work and rounds). The majority of

observed tasks consisted of routine care, followed by less frequent tasks such as blood work, total parenteral nutrition (TPN) set up, tracheal intubation, a lumbar puncture procedure, housekeeping, supply management and rounds. Question guides, field note templates, a sketch pad, digital camera and measuring tape were used in documentation.

3.2.3. Thematic analysis

Thematic analysis was conducted concurrently to help inform and focus subsequent data collection. The researcher transcribed hand written field notes to a digital document following each meeting and observation session, tagged the data with process codes and wrote memos. Codes were grouped into themes and visually networked.

Preliminary findings were shared in a meeting with staff representatives (4 nurses, 1 care facilitator, 2 nurse educators, 1 infection prevention and control specialist, 2 neonatologists, clinical manager and unit director) in order to understand and document whether the findings resonated with their views and experiences. Following this meeting, this additional data, relevant literature and the analysis were reviewed to finalise the framework and develop recommendations.

4. Findings

The documentation consisted of c.5000 words of meeting notes and codes, c.46,000 words of observation documentation and codes, c.3000 words of researcher memos and 497 photos. An instance count of codes related to IPAC and breaches was also conducted to compare to the thematic network. Frequent words included equipment, furniture, supplies, drawers, bedside counter, isolette, chart and waste. Although the count does not indicate why the words were frequent, their dominance suggests these specific items are worth further study.

4.1. Results from the planning phase

Findings from the planning phase were organised in layers starting with stakeholders outward to the larger context (Figure 5). This work revealed that HCWs have created work-arounds to deal with the constraints and poor conditions posed by the existing design. See Table 1 for more detailed results.

Figure 5. The Planning Stage helped establish background information on the people involved in the study, tasks, immediate environment as well as larger contextual information.

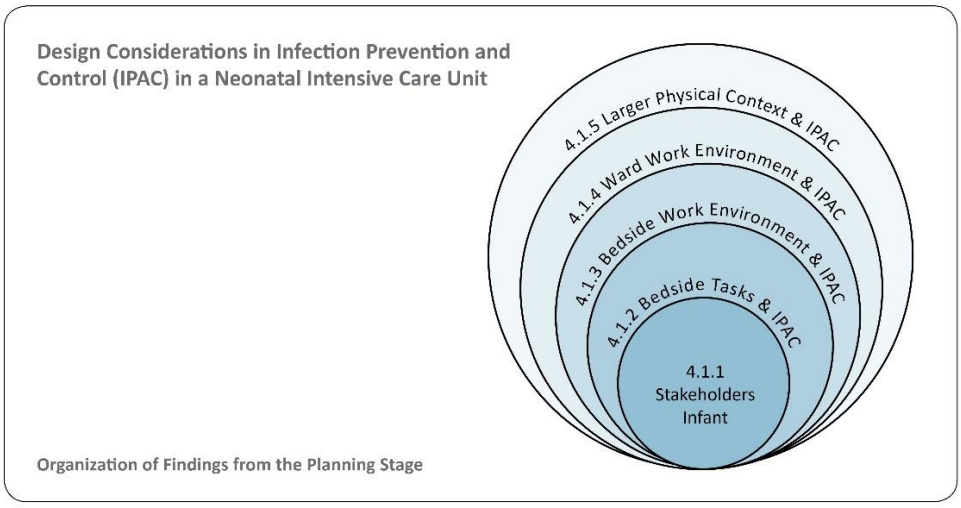


Table 1. Results from the planning phase.

Table 1: Results from Planning Phase	
Context Layer	Findings from Planning Meetings and Site Documentation
4.1.1 Stakeholders	Stakeholders were identified during planning (see Figure 6), focusing on HCWs with close and frequent access to the bedside such as nursing staff, respiratory therapists, housekeeping staff, supply logistics workers and rounds staff. Family members were excluded from the study but their presence was noted in understanding spatial or other relevant considerations. Other stakeholders (e.g. facilities staff) were not studied due to lack of availability.
4.1.2 Bedside Tasks and IPAC	Bedside tasks involves processes that occur at the bed and immediate area adjacent to the bed area (e.g. bedside work counter). Stakeholders explained in meetings that despite being fully aware of the "five moments of hand hygiene" prescribed for NICUs (Figure 2), they could not adopt the practice because the neonate environment (i.e.

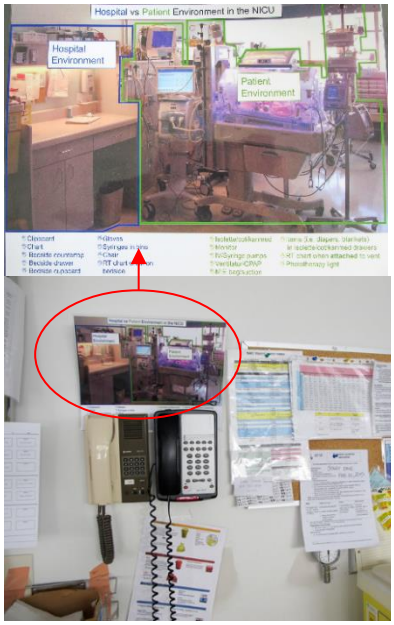
	isolettes, warmers, cots) was not designed to hold ABHR. They further explained that performing hand hygiene was complicated by managing equipment alarms and supplies outside the neonate environment. Alarms go off frequently and in the event that staff are required to leave the neonate environment to 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. Stakeholders explained that alarms may go off while HCWs' hands are occupied holding a supply 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, on top of or in the bed.
4.1.3 Bedside Work Environment and IPAC	The bedside work environment in this study is defined as the bed and the area immediately surrounding the bed area (e.g. bedside work counter, equipment). The unit experimented with adding off-the-shelf ABHR holders to the beds but since they were not permanently fixed, they would go missing and were expensive to replace. Similarly, wearable ABHR was not considered due to cost and concern for misplacement. In light of such challenges, the unit collaborated with IPAC specialists to develop a less stringent model requiring hand hygiene before entering the PE and upon exiting the PE which included designating specific items within the work area to the PE and HE zones. Guidance is provided on what to do if HCWs are in breach of the rule, asking them to wipe down items in the PE that have been touched without performing hand hygiene with a germicidal wipe immediately upon realization of the breach. Findings from the planning stage showed the quantity of supplies used per shift was much lower than the amount that is typically stocked. Of the 19 supply checklists returned to the researcher, actual supply use ranged from 14 individual supplies used for one lower acuity case up to 51 supplies used for a higher acuity case. The most frequently used supplies were gauze, syringes, Qtips, gloves and medicine cups.
4.1.4 Ward Work Environment and IPAC	The unit consists of three wards occupied by infants of varying acuity, from higher acuity (premature infants) to lower acuity (infants close to going home or a step down unit). Higher acuity infants have approximately 9.3 square meters (sm) or 100 square feet (sf), followed by 4.6sm (50 sf) for more stable infants and 3sm (32 sf) for the lower acuity patients. Lower acuity beds have approximately 1220 -1370 mm (4-4.5 ft) of space in between them whereas higher acuity beds have approximately 1830 mm (6 ft). These numbers fall below the recommended 11.2sm (120 sf) of clear floor space and 2.4m (8 ft) distance required between isolettes/warmers (Public Health Ontario, 2012a). Although hand hygiene sinks were located near entries and within the recommended 6 m (20 ft) of infant beds (White, 2012), the sinks have inconsistent controls, were improperly sealed to walls and created excessive splashing in some cases.
4.1.5 Larger Physical Context and IPAC	First impressions of the site were documented using the ISO's Expert Assessment of the Physical Environment Tool. Most striking was the spatial and visual congestion of the layout, millwork, equipment, furniture and documents posted on walls; the worn appearance of various surfaces; inconsistent faucet controls, sinks and accessory layout at hand hygiene sink areas with general consistency in ABHR layout at the bedside; little adaptive opportunity for staff to adjust the environment due to space constraints and fixed items; poor lighting conditions (high glare and dark zones); the smell of hand sanitizer; and the continuous sound of alarms from equipment.

4.2. Results from naturalistic observation and concurrent thematic analysis

Observations and thematic analysis revealed that some staff engaged knowingly and unknowingly in unsafe behaviour with regard to infection prevention. The study also revealed that some staff expended a great deal of effort to 'maintain a safe line, or space' between the hospital and the patient environment by wiping down surfaces with germicidal wipes, performing hand hygiene at the right moment, and in some cases, performing hand hygiene more than would be required. The key subthemes (see Table 2) that emerged in this preliminary analysis suggest:

- an extensive range of high touch surfaces and objects may be covertly transmitting pathogens and compromising the ability to maintain barriers between the PE and the HE and also 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 which may be positively and/or negatively influencing infection prevention practice (e.g. control over IPAC vs. increased workload);
- nurses' need to feel prepared and complete tasks in a timely manner may take priority over optimal infection prevention practice, suggesting better supports and processes are required to reduce, simplify and/or slow down steps in their work process to meet this need while facilitating safer behaviour; and
- healthcare workers' understanding or 'mental models' of the rules to support infection prevention and their understanding of the risk of infectious outcomes associated with their behaviour may be influencing practice.

Table 2. Results from the naturalistic observation phase.

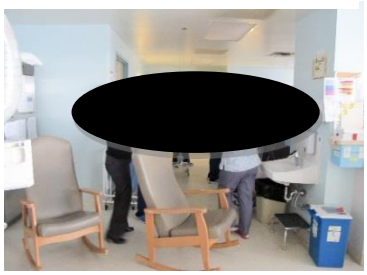
Table 2: Results from Naturalistic Observation Phase	
Theme	Findings from Naturalistic Observation Phase
4.4.1 Representations or Mental Models of Infection Prevention Measures  *Figure 4.2.5 a – The zoning map developed to help health care workers distinguish between the patient and hospital environment. No provision has been given to incorporating aids at the point-of-care and maps are lost in visual clutter of other postings.*	Observations revealed staff having different understandings of infection prevention. The following scenario illustrates the diversity of mental models amongst HCWs through a composite persona which is based on observations and feedback from various nurses who participated in the study. A NICU nurse is covering for her colleague who is on break and is managing the care of several infants. One infant is on contact precautions which requires donning PPE to enter the patient's environment. The alarm on the physiological monitor which is part of the PE is ringing. Meanwhile, the alarms on other infants' monitors are also ringing, infants are perhaps crying and the nurse is in the middle of a task. In order to act under such circumstances, it is reasonable to assume that this nurse will draw upon a mental model of the situation, the people and the elements in her environment in order to act. Best practice requires the nurse to don PPE prior to entering the PE. The nurse may have a good understanding of IPAC requirements but the mental model guiding her behaviour may be faulty (she may neglect to put on the PPE in order to save time and silence the monitor), it may be incomplete (she may not know how to best handle the situation), it may be useful (she may come up with a new way to silence the monitor without entering the PE) or it may be consistent with the mental models of authority (she may choose to ask a colleague for help with the other infants and put on PPE before silencing the monitor). If we accept the idea that mental models exist and are relevant to IPAC, what the scenario illustrates is that not only are we drawing on a mental model to act, but there may be multiple models, inconsistent models within an individual, or inconsistent models among individuals, all seemingly working under the guise of achieving a common goal. In discussing breaches, the PE/HE diagram was reviewed by some staff, suggesting the distinctions and actions required between zones were not clear to them. Some HCWs had trouble finding the diagram among other postings (see Figure 4.2.5a). Observations also revealed a perception or an attempt to maintain the belief that objects such as the supply drawers, chairs and counter are ‘clean’ and that indirect contact between such areas and the infant was 'safe'. This varied among HCWs, with some staff seeing the areas as 'compromised' and others seeing the areas as 'clean'. Some nurses felt the drawers were compromised since they rarely get cleaned and supplies don't get discarded when a patient is discharged. Observations suggested the mental models of housekeeping staff may also be faulty or incomplete since one rag would be used to wipe both soiled and clean areas or across multiple patient bays. When one housekeeper was asked if she knew the distinction between the PE and HE she stated she was not aware of the PE/HE diagram. Refer to the quotes below and Figure 4.2.5a for examples which illustrate how mental models of IPAC may be informing practice. ***Quote 1:*** *Nurse O - “the supplies are supposed to be clean”.* ***Quote 2:*** *Nurse C - “If we wiped down the arms [of the chair] it becomes the infant’s environment.”* ***Quote 3:*** *Researcher - “I noticed you did not Purell before checking the equipment."* *Nurse M - “It’s all clean”...motioning to the counter...“it’s part of his environment.”* *Researcher - “But isn’t it the hospital environment, the chart as well?”* *Nurse M - “I don’t know, I can’t remember the diagram.”* *Researcher - We walk over to the diagram and look at it.* *Nurse M - “Oh, it is hospital environment. I should have Purelled then.”*
4.4.2 Work Motivation	Observations revealed nurses share a strong sense of needing to complete a task, with some staff members commenting that breaches are most likely to occur when “you’re in the middle of something” or “you have everything set up and you just need that one thing” or “the infant is not doing well” and you grab a supply or go into the drawers. Stocking supplies in drawers requires staff to touch multiple surfaces to get supplies and complete a task. Some nurses suggested moving to more limited supplies and having them more accessible so that nurses don't need to touch multiple surfaces to get to them. Nurses engage in multiple steps to complete a task and some appear to experience occlusion in completing tasks, forgetting to perform hand hygiene or perceiving hand hygiene as interrupting their ability to complete their work in a timely manner. Refer to the quotes below illustrating this theme.

Quote 1:
Researcher - "Do you see any issues with the design of your work counter area beside the infants with regards to infection prevention? Are there concerns with the millwork counter and cabinets, furniture, or equipment?"
Nurse I - "Certainly the drawers, my goodness"... "we reach and grab" ... "it should be readily available"... "I've seen holders for gloves which allow you to pull one at time without touching anything".
Quote 2:
Researcher Observation - Nurse J puts on the protective apron, Purells, waits a bit, puts on gloves and moves towards the left side of infant's isolette to assist with the x-ray. Nurse J gently nudges the family chair with her gloves to get past it to access the isolette. No one is close to her so I immediately rush over and quietly tell Nurse J she has touch the chair with her gloves. She's looks calm and does not enter the isolette, removes her gloves and walks to the Purell on the other side of the isolette.
Nurse E - "We're so busy", as she Purells and puts on another pair of gloves.

4.4.3 Influence of High Touch Items

Figure 4.2.1a, 4.2.1b above - Examples of how nurses try to isolate sterile supplies from high touch surfaces like work counters and the flow sheet/chart.

Figure 4.2.1c below – Example of chairs used for infant care. High touch areas include the arms and back of the chair. Chairs are often moved out of the way or towards the isolette to perform tasks.



Inadvertent contact between PE and HE items (e.g. chart or counter touching gloves or supplies used in the PE) and lack of hand hygiene between the PE and the HE (e.g. grabbing supplies in drawers with gloved hands, then going into the PE) contributed to lapses in infection prevention practice. The exterior surfaces of the bedside counter are disinfected with a germicidal wipe by nurses at the beginning of every shift, but after that are touched by various HE items and people. The importance of establishing an isolated, protected, clean 'space' on the counter became apparent during observations (see Figures 4.2.1a, 4.2.1b). Nurses 'carved out a little space' typically in the corner closest to the bedside to organize and isolate sterile supplies from the HE. Sometimes the supplies were further isolated from the counter by placing them in medicine cups or on the exterior of sterile packaging. The chart which shares this space and is part of the HE is integral to completing bedside tasks since nurses are continually charting information from the equipment interface requiring them to be close to the equipment. The chart also acts as a situation awareness tool prompting task initiation and completion.

Due to the crowded condition of the unit, staff were continually and inadvertently touching and moving items such as chairs and equipment out of the way of their tasks, sometimes just prior to entering the PE without performing hand hygiene. In some cases, equipment designated to one infant was moved into other infant bays to create space to work or for family. Staff feed and handle infants in chairs which are shared and observations revealed the chairs don't get wiped down in between use, and at best, once a day by cleaning staff. Various handles were touched throughout tasks often without ABHR within reach (e.g. clean and soiled storage room doors, milk fridge doors, faucet taps used to fill milk buckets and infant baths, cabinets for clean linens and PPE, supply drawers). See Figure 4.2.1a, 4.2.1b, 4.2.1c and quotes which illustrate how high touch items may be informing practice.

Quote 1:
Nurse B - "We're constantly turning off alarms. But they're programmed to go off too often."
Quote 2:
Researcher - "The gloves were on the chart. Are you about to use them in the infant's environment? Is this a breach?"
Researcher Observation - Nurse F and Nurse G look a little confused but then agree that it is. Nurse G disposes of the gloves.
Nurse F - "We Virox the counter at the beginning of the shift as a precaution but yes the chart is on it."
Nurse F - "The chart is dirty but we need a clean space to prep out things. What if we put a line down our counter with the clean space on the left [closest to the infant] and the chart on the right?"

4.4.4 Physical and Cognitive Exertion

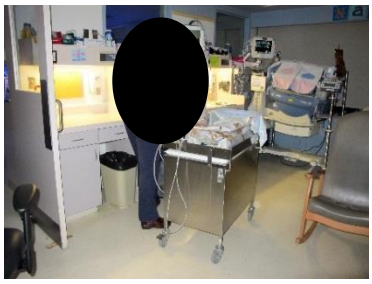


Figure 4.2.2a - A taller nurse bending forward to perform routine care on a cot that is not height adjustable. The duration of this task is 30min-1 hour and occurs every two-four hours over the course of 12 hours. Some nurses raise the infant on higher surfaces to perform their work due to discomfort.

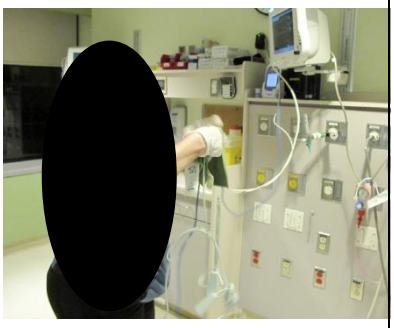


Figure 4.2.2b - A housekeeper cleaning cables on physiological monitor in preparation for a new patient.

Nurses are expending energy and time hand sanitizing; holding awkward postures to reach items; standing on hard floors under poor lighting; walking, moving, organizing and cleaning items due to lack of space, poor layout, poor conditions, to silence alarms or cover staff on breaks. Support staff are scarce, also work in awkward positions and handle heavy objects. There is only one dedicated housekeeper for weekdays and one for evenings, and the latter's job role is limited to emptying waste, restocking ABHR and cleaning infant bays for new admits when required. The design requires staff to reach and bend awkwardly to clean and organize which may negatively influence their ability to clean well. There is only one dedicated supply logistic worker working weekdays. Casual or part-time staff typically work weekends, filling in for permanent staff and may not understand IPAC distinctions. See Figure 4.2.2a and 4.2.2b and quotes which illustrate how high touch items may be informing practice.

Quote 1:
Researcher - Nurse D goes to infant bay A which is the infant under her care and gets a pen. She comes back to input information in the other infant's chart which she leans over to work on. She moves the pen and calculator between bays. She eventually finds the calculator tucked up high on the top of a shelf located above the bedside work counter of an infant bay and offers the following explanation.
Nurse D - "The calculator's Velcro is worn off and missing so it can be attached to the counter anymore. So someone, who's maybe a bit taller, has put it up here, but it's difficult to see."

Quote 2:
Researcher Observation - I watch the process for cleaning an infant bay. The housekeeper leaves the cart in the main corridor. She removes her gloves, puts on new gloves and uses #12 cleaner. She starts with the cables which are continually falling to the floor. The process looks difficult and cumbersome.
Housekeeper A - As she does this *"they should have a hook for these we can tie them around so they don't fall."*

4.4.5

Expanding Job Design to Manage Environment and IPAC

Figure 4.2.3 a - Example of nurse folding linens which in the past was done by volunteers. No layout space is available to do this task which she does on her lap.

Observations revealed nursing duties have expanded beyond bedside care to include housekeeping and stocking. Aside from disinfecting their work areas with germicidal wipes at the beginning of each shift, nurses must disinfect shared equipment prior to each use (e.g. weigh scales). Some nurses commented that they sometimes wipe down surfaces that have just been cleaned by housekeeping staff because they notice breaches in cleaning practices such as using the same rag to clean soiled areas and hand wash sinks. Nurses are also required to fold clean linen and stock it, a task that used to be performed by laundry services. See Figure 4.2.3a and quotes below which illustrate this theme.

Quote 1:
Researcher Observation - Nurse C goes looking for the infant weigh scale which is in the corridor (hospital environment), brings it back and wipes it down with Virox wipes.
Researcher - "Can you tell me why you're wiping down the scale?"
Nurse C - "It's most likely been wiped down but we can't be sure, especially in the hallway...someone might have touched it or leaned up against it."

Quote 2:
Nurse A - "We used to have volunteers on the unit who would help out with these things. They would come around with a cart with folded linen and ask us what we needed. That was helpful but was taken away some time ago. I think retired nurses would be happy to come back as volunteers to help out, hold infants...I would do this."

4.3. Feedback meeting on preliminary findings

A meeting with staff representatives revealed that the findings 'validated what we have known for a long time' and sketches and other media developed to prompt feedback led to discussions on areas for future design exploration.

4.4. Thematic analysis – final proposed framework and Design exploration guide

The study revealed that *the design of the environment may be undermining HCWs' understanding and practice of rules that can support IPAC and their understanding of risk of infectious outcomes associated with their behaviour*. Variations and breaches in IPAC among HCWs are fuelled by an absence of design attributes and supports that may help clarify how to practice IPAC, clarify transmission risks and better facilitate work objectives to support safer behaviour. This finding was originally presented in a conference paper by Trudel et al. (2016) and the thematic framework has since been refined for this article, providing additional details on design and practice influences and outcomes related to IPAC as described below[Figure 6].

Figure 6. Framework of findings – NICU IPAC study.

The two main outcomes from the thematic analysis were:

- a 'Framework of Findings – NICU IPAC Study' which outlines the core theme and relationships between subthemes (Figure 6); and
- the 'NICU IPAC Design Exploration Guide – Detailed Findings and Recommendations', a detailed 24-page/c. 7200-word document identifying specific issues to facilitate future study and design development (discussed elsewhere).

4.4.1. Understanding of IPAC

The study revealed that HCWs do not share a uniform interpretation of the rules that can help support IPAC or infectious risks associated with their behaviour. These representations or 'mental models' of IPAC varied in the study – some were functional while others were hazy or faulty (i.e. not aligned with unit protocols).

Despite the previous efforts of nurse educators and infection prevention specialists to convey a functional model of best practice in IPAC and infectious risk outcomes through training and visual/text-based aids, the design of the environment undermines this initiative. For example, crowded conditions blur the line that educators have tried to establish between infection transmission zones, bring people closer to potentially contaminated surfaces and result in the movement and potential cross-contamination of equipment, furniture and accessories between zones to clear areas for working or family participation. Cues or affordances that might otherwise help HCWs understand infection transmission zones and behaviours required between zones to reduce the risk of infectious outcomes are absent. Further, the potential for training aids is compromised by the lack of education display space at key decision-making points (e.g. point-of-care) and congested display spaces. Working within the context of such deficiencies, it is not surprising that functional models of good practice in IPAC and potential risks associated with behaviour are difficult to form, instantiate or consistently maintain.

4.4.2. Work objectives and motivations

If HCWs feel stressed and pressed for time, they may resist a functional mental model of IPAC and instead instantiate a faulty mental model that allows them to work more quickly. In some cases, completing a task took priority over the possibility of contributing to infectious outcomes, since nurses perceived IPAC 'rules' (e.g. hand hygiene or disinfecting) to be impeding their ability to perform their work. This perception may be fuelled by the effort and frequent number of steps required to uphold barriers to transmission within an already demanding job. Similarly, the study revealed that feeling prepared for a potential decline in an infant's health justified going into the drawers for supplies without performing hand hygiene. Yet some nurses had their supplies prepared on top of the counter in preparation for patient decline and in one exemplary case, a nurse performed hand hygiene more than required because, from her perspective, it was better to be over-cautious. Nurse educators were aware of the issue, emphasising how IPAC training must incorporate the message that 'nurses need to slow down their work'. From a systems perspective, the feasibility of slowing down the work process must be considered within the context of the existing job design and demands. When the lives of infants are potentially at stake, it may be challenging to convince nurses to slow down. However, the motivation to take shortcuts in IPAC can perhaps be tamed by designs that help strengthen a functional mental model or emphasise the associated risks when functional models are neglected.

4.4.3. Objects/surfaces used in practice

As mental models are instantiated, HCWs must navigate through a variety of 'high touch', possibly contaminated, items within tight spatial constraints to perform their work. Models of IPAC can guide HCW interactions with such items and faulty or incomplete mental models may lead to poor behavioural choices which compromise infection prevention (e.g. placing a glove about to be used in the isolette on a flow sheet/chart). But even with a functional mental model, HCWs may compromise safety due to unintentional interactions with high touch items (e.g. inadvertently brushing a gloved hand against a chair to move it out of the way prior to entering the isolette). This highlights the importance of space efficiencies in layout and

product design and clearly delineating surfaces or objects that carry transmission risks in critical environments.

4.4.4. Environmental influences on daily practice

Deficiencies in layout and equipment design resulted in staff continually searching, getting and relocating items or moving quickly to complete tasks. Hard floor surfaces and few seating areas result in staff resting against counters or soiled linen carts. HCWs reach above their shoulders or bend down low to clean and retrieve items. The condition of the environment (e.g. porous, worn surfaces or fussy details) may harbour pathogens, be difficult to clean and decrease staff's motivation to keep it clean and organised.

4.4.5. Influence of job design compensating for lack of environmental IPAC barriers

Increased vigilance required in IPAC, poor environmental conditions and reduced support staff result in nurses having to frequently disinfect surfaces, retrieve and stock items, and rearrange the layout of the environment to conduct various tasks. Although nurses may maintain greater control and awareness over infection prevention measures in doing such tasks, the additional duties may be taxing an already demanding profession and diverting attention and energy away from primary care and IPAC practice. These activities also introduce new opportunities for contact with infectious organisms.

5. Discussion

The analysis revealed that HCWs hold different interpretations or mental models of IPAC, a finding supported by Pittet (2001), Pessoa-Silva et al. (2007) and Sax and Clack (2015) who suggested individuals have different perceptions of IPAC which may play a role in infection prevention practice. Challenges with high touch surfaces have been noted by Huslage et al. (2010) and our study showed that the risks associated with high touch surfaces may become even more pronounced within the context of faulty or hazy mental models, the need to feel prepared and complete tasks in a timely manner, environmental constraints (space, excessive physical and cognitive exertion) and extensions to job design which require more contact interactions.

Our findings support the work of previous authors who discuss the negative impact of crowding (e.g. Archibald et al. 1997) as well as time constraints, pace of work, high workload and understaffing (Archibald et al. 1997; Pittet 2001; Ulrich et al. 2004) on infection prevention practice. The preoccupation with meeting objectives centred on achieving immediate care goals at the expense of future potential infectious outcomes supports early studies which showed that HCWs prioritised patient needs over hand hygiene (Pittet 2001) and perceptions that transmission risks are low (e.g. Pittet 2001; Bryant, McLaughlin, and Walsh 2012). Specifically, the study revealed the importance of managing, accessing and isolating supplies from other surfaces, which has been identified in previous studies (e.g. Hendrich 2003 and Ulrich et al. 2004); and reducing supply stock to decrease the likelihood of using overstock on infants. Recent studies have drawn attention to supply management (e.g. Bazuin et al. 2015), suggesting that a reduction in supply use and associated costs may contribute to a reduction in HAIs within the unit (Morrow et al. 2013). Although specific themes such as 'hand hygiene', high touch items' or 'mental models' have been the subject of previous studies, the framework generated from our study illustrates the inter-relationships between themes and therefore the importance of a holistic approach to design review.

5.1. Limitations of the study design

As the researcher had no formal training in hand hygiene observation and limited clinical knowledge, this may have influenced a sensitivity to detecting breaches and aspects of clinical processes influencing breaches. The study may have benefited from inter-observer reliability and the Hawthorne effect should be acknowledged for potentially influencing positive behaviour during observations (Robson 2011). However, open, anonymous discussions on breaches with participants may have supported more natural and authentic behaviour than if the study had been an audit, for example. Although manual note-taking

was preferred due to lack of space and seating, the method was inadequate to fully record the rapid pace of work and multiple interactions (FitzGerald, Moore, and Wilson 2013).

6. Conclusion

The study set out to develop an understanding of infection prevention and control issues related to the design of the environment within an existing neonatal intensive care unit using pre-design empirical inquiry methods such as stakeholder meetings, naturalistic observation and a concurrent process of thematic analysis. The use of a human-centred approach generated a framework for understanding factors that may contribute to breaches in infection prevention and control. The findings revealed that healthcare workers vary in their understanding of infection prevention and also that IPAC may be undermined by well-intentioned behavioural attitudes to meeting work objectives, expanding job descriptions, high touch interactions with designs as well as physical and cognitive exertion to manage the environment. The study, framework and guidelines have been shared with the hospital leadership team and the organisation is working towards a major renovation of the unit to address these challenges. In the wider context, it is considered that the framework may help healthcare workers and designers work through the complexities of fostering optimal behaviour in infection prevention practice and provide impetus for conducting pre-design inquiry.

Future research includes developing and testing workspace and product designs that: support work objectives and functional mental models of IPAC; reduce high touch interactions as well as physical and cognitive exertion; and can be assessed using statistical analysis of pre- and post-interventions. Specifically, this would include experimenting with designs that provide feedback, make infection prevention risks and processes more visible and the use of metaphors to enhance learning and practice (Wickens et al. 2004). Within the wider context of social engineering, this research supports the importance of acquiring and fostering a safety culture which values: vigilance in detecting factors that may weaken an organisation's defences; ongoing data collection to inform decision-making; worker participation in development, exposing errors and near-misses; a clear and just approach to safe and unsafe behaviour; and an ongoing commitment to promoting a learning culture that can self-diagnose and self-correct (Reason 1997; Rosen et al. 2012).

The issues identified in this study are not unique or localised. Other settings may find it difficult to achieve best practice or competence, particularly when design does not support IPAC (Petty 2014). This study aimed to contribute to our general knowledge of IPAC challenges within the design of healthcare environments and provide insight into the value of using empirical inquiry at an early stage and, ideally, prior to the design process.

Disclosure statement

No potential conflict of interest was reported by the authors.

Acknowledgements

Thanks are given to all the staff from the neonatal intensive care unit who participated in this study, Christine Smith, Lucie Charron, Joyce Mackay Perry, Louise Dufort, Barbara Foote, Dr. Stephanie Redpath, Dr. Brigitte Lemyre, Nathalie Bruce, Michele Larocque-Levac, Debra Bournes, Heather McDonald, Ruth Rennicks White and Dr. Kathryn Suh.

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