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A human factors engineering approach to improving hand hygiene quality

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ABSTRACT

Healthcare-associated infections (HAIs) are common and expensive complications that can occur during inpatient hospital stays. Hand hygiene (HH)—which includes hand washing with soap and water and hand rubbing with alcohol-based hand sanitizer—is the primary tool used by healthcare personnel (HCP) to prevent HAIs. Consequently, the World Health Organization (WHO) proposed guidelines for effective HH in healthcare settings. However, consistent performance of HH by HCP is still lacking. HH in healthcare requires both compliance with indications for HH and quality of HH. Integrative approaches in human factors engineering (HFE) and infection prevention can be used to promote sustainable techniques that can be implemented by HCP to improve the quality of HH techniques. This research proposes a three-phase integrative approach that uses HFE-based methods to identify why HH is often insufficiently executed by HCP in hospital settings and ultimately to help guide HCP to improve HH quality. We performed i) a tabular task analysis (TTA), constructed by HFE personnel and infection prevention specialists, ii) card sorting with infection prevention subject matter experts to prioritize HH steps and analyzed with criticality analysis and subsequent modifications to the TTA, and iii) TTA validation and verification with subject matter experts. Finally, we conducted qualitative interviews with members of hospital leadership and determined that it is feasible to implement the use of TTAs in hospital settings. This research provides enhanced HH guidance using an integrative HFE-based approach and is directed to increase the quality of HH performed by HCP, thereby reducing HAI rates and improving patient safety. Furthermore, these results can be used to support the effective implementation of the WHO's HH guidance. Our findings elucidate some of the challenges to patient safety regarding HH and clarify best practices for HH in hospital settings.

Introduction

Hospitalized patients are at risk for acquiring healthcare-associated infections (HAIs) (Alhumaid et al., 2021, Stewart et al., 2021), the global prevalence of which has been estimated to be as high as 15.5%, affecting up to 687,000 people resulting in 72,000 deaths in the US annually (Allegranzi et al., 2011; World Health Organization, 2011, Centers for Disease Control and Prevention, 2023a; Klevens et al., 2007). Although these infections may result from pathogens carried by the patient, causative pathogens of an HAI may also be acquired from another patient, healthcare personnel (HCP), or contaminated surfaces in the built healthcare environment (Glowicz et al., 2023). The primary tool to prevent the spread of these infections is hand hygiene (HH), which is performed by either of two methods to mitigate the transmission of microbes via direct hand-to-hand contact: hand washing with soap and water or hand rubbing with alcohol-based hand sanitizer (ABHS) (Boyce, 2019, 2021; Glowicz et al., 2023; Mathur, 2011). Although the importance of following appropriate HH protocols has been well documented, consistent implementation of HH technique in healthcare settings is lacking (e.g., Boyce & Pittet, 2002; Boyce, 2023; Hillier, 2020; Sickbert-Bennett et al., 2016a) and the integration of human factors engineering concepts and techniques in healthcare is also lagging (Gurses et al., 2022).

This research aims to focus on improving hand hygiene quality for HCP to reduce HAIs in healthcare settings.

Hand hygiene to prevent HAI

The safety culture surrounding healthcare processes has suffered owing to decreases in hospital staffing and the increased patient complexity (Fleisher et al., 2022).

Investment in HH programs and infrastructure could improve patient outcomes by reducing HAIs, also leading to improved patient outcomes and cost savings. An examination of the global HAI burden and infection

Abbreviations: ABHS, alcohol-based hand sanitizer; CDC, centers for disease control and prevention; HAIs, healthcare-associated infections; HCP, healthcare personnel; HFE, human factors engineering; HH, hand hygiene; HHS, U.S. department of health and human services; HIPSTER, high impact pathogens: Surveillance, training and emergency response; IP, infection prevention; SHEA, society for healthcare epidemiology of America; SMEs, subject matter experts; SEIPS, systems engineering initiative for patient safety; TTA, tabular task analysis; WHO, world health organization; YNHHS, yale new haven health system.

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prevention strategies found significantly reduced HAIs when HH guidelines were consistently followed (Grayson et al., 2009, Barker et al., 2020, Price et al., 2018).

Hand hygiene guidelines and implementation in healthcare

A common way to facilitate training for new processes (e.g., HH) is through step-by-step guides that emphasize key actions of importance. As a result of the low HCP compliance rate with HH best practices

Fig. 1. "How to Handrub?" poster for using alcohol-based hand sanitizer developed by the World Health Organization. Copyright permission pending.

despite the known benefits of HH, the WHO recommends incorporating HH as an assessment standard in healthcare (World Health Organization, 2023). The WHO guidelines, exemplified by the slogan "My 5 Moments for Hand Hygiene" for healthcare settings, have received recognition as a good foundation for optimal HH practices (Lotfinejad et al., 2020.

In a publication on the HH research agenda in healthcare for 2023–2030 (World Health Organization, 2023), the WHO clarified the primary approaches that should be used for proper HH. Essential methods include handwashing with soap and water or employing ABHS (Fig. 1), the latter of which is preferred in most clinical situations, because it is faster to perform, more effective, can be readily available at the point of patient care, and is often better tolerated than soap and water (Boyce & Pittet, 2002; WHO, 2009, Centers for Disease Control and Prevention, 2022). These WHO guidelines stress proper HH at key moments during patient care, which include before touching a patient, before a procedure, after body fluid exposure risk, after touching a patient, and after touching a patient's surroundings.

Moreover, both the WHO (via their "How to Handrub?" poster; Fig. 1) and the CDC (via their "Hand Hygiene in Healthcare Settings" program; Centers for Disease Control and Prevention, 2023b) have also focused on promoting the proper use of ABHS.

However, adherence remains a challenge, and key barriers include demanding workloads, time constraints, and limited access to HH facilities (Gould et al., 2020; and Mohamed and Ali, 2023). Interventions such as education, awareness campaigns, reminders, and patient engagement, have been proposed to overcome barriers to HH compliance (Singh & Barnard., 2023, Stone, 2018, Valim et al., 2019, Chandonnet et al., 2017; Lee et al., 2021; Linam et al., 2019; Pires et al., 2021).

Lapses in HH technique are common causes of ineffective HH, even when compliance is high. When participants unfamiliar with the WHO hand-rub poster (Fig. 1) performed HH after education, the majority failed to achieve adequate skin coverage. This was mitigated by poster redesign, supporting technique as a major cause of HH failure (Durso et al., 2021). Deficiencies in achieving full skin coverage occur even in the six-step procedure, with certain steps being more important to skin coverage than others (Wang et al., 2022). Additionally, there may be higher HH compliance with a three-step hand rub procedure compared with the conventional six-step procedure (Tschudin-Sutter et al., 2019), as fewer steps may increase compliance without compromising quality. Another study observed high HH compliance, but inadequate skin coverage in over 90% of tested healthcare workers (Park et al., 2014). Thus, optimal HH requires both high event compliance with the indications, as well as appropriate technique to ensure adequate skin disinfection to prevent HAI transmission. Of note, the Leapfrog Group, a major US patient safety assessment and reporting organization, surveys healthcare organizations regarding the duration of hand hygiene, the coverage of all aspects of staff hands during hand hygiene performance, and whether performance improvement includes the demonstration of hand hygiene performance by staff (Leapfrog Group, 2024).

Human factors engineering to improve hand hygiene quality

Human factors engineering (HFE) approaches—which are used to assess human capability, technology use, and the incorporation of process optimization (Licht et al., 1989)—can provide valuable and feasible methodologies, processes, and pathways for improving HH quality (Gurses et al., 2020, 2022; Jacob et al., 2018).

Although workplace culture varies among units within healthcare and variation is anticipated between facilities and settings (Agency for Healthcare Research and Quality, 2022), there are examples of workplace cultures where personnel are encouraged to provide feedback on HH behavior across roles (e.g., Sickbert-Bennett et al., 2016a, 2016b). Examining HH compliance revealed a need to challenge both the attitudes and norms surrounding HH quality, including the importance of emphasizing how lapses can lead to the transmission of infections.

Although studies show that education and training-based approaches to improving HH quality by HCP (e.g., simplifying language, appealing to sense of patient care, and more salient and visible visual aids) contributed to decreases in HAIs (e.g., Dunn-Navarra et al., 2011; Hanh et al., 2015; Lee et al., 2011; Lotfinejad et al., 2021; Voss & Widmer, 1997), researchers have not identified a specific HFE approach that best mitigates barriers to performing high quality HH. Furthermore, as existing guidelines and graphics are i) geared towards non-HCP (i.e., CDC guidelines), ii) use unfamiliar terminology (i.e., WHO guidelines), and iii) and lack detail on precise timelines and volumes of soap/ABHS (i.e., both CDC and WHO guidelines), explicit procedures and directives have not been described to best promote proficient HH by HCP. Studies conducted by Durso et al., 2021 and Wang, *et al.* 2022 recommended that current WHO instructions be revised to be more clear, detailed, and provide step-by-step instructions for HCP.

One solution is through a HFE-based task analysis. Task analyses involve collecting task data, breaking down each aspect of those data to help determine sources of human error, and then producing representations of the tasks analyzed (Hollnagel, 2021; Stanton, *et al.*, 2017). A task analysis in a tabular format is known as a tabular task analysis (TTA), which is a detailed analysis method in HFE (Stanton, 2006; Stanton, *et al.*, 2017). A TTA provides a written step-by-step understanding of the impacts, harms, and potential solutions as an end user works through a task (U.S. Department of Health and Human Services, 2016). This tool breaks down all steps required to complete a specific task and can be used to elucidate the human, technological, and environmental constraints of the HH process because it focuses on the individual actions and the user needs, harms, and proposed solutions. Using TTAs in healthcare can provide leadership with a tool that can be incorporated for risk management at a system level (Catchpole, *et al.*, 2021).

Thus, to improve HH quality, we developed a three-phase HFE-based approach. These phases included constructing a TTA to break down WHO guidelines into subtasks (steps), card sorting with criticality analysis to identify the most important HH steps that need to be emphasized in a TTA, and interviews with hospital leadership to identify the potential of implementing a TTA-based approach to improve the quality of HH. . Therefore, our study will i) help clarify best practices for implementing HH quality by HCP in hospital settings, and ii) provide a foundation for future research on HH process optimization. The present study focuses primarily on ABHS owing to the increased use of ABHS compared to soap and water i, as well as the high incidence of improper ABHS use and factors that complicate effective ABHS-based HH (e.g., hand size) (Boyce and Martinello, 2022; Martinello, *et al.*, 2019).

Problem statement

As improper HH during patient care leads to increased HAIs, it is vital to close the gap between existing HH resources and the needs of HCP in hospital settings. Although WHO guidelines explain how to properly perform HH, quality is not emphasized. To address this gap, this study describes a novel, integrative, HFE-based approach that can be used to optimize the HH process. Surveys performed by hospital leadership indicated that this approach holds promise for implementation in hospital settings.

Materials and methods

This research was structured into three phases using HFE techniques: i) phase 1, TTA construction; ii) phase 2, card sorting, criticality analysis, and TTA validation and verification; and iii) phase 3, qualitative interviews with hospital physicians and nursing leadership. All research was conducted in a single health system, the Yale New Haven Health System (YNHHS). A health system for the purposes of this research, is defined as a group of hospitals under the same managerial oversight.

The study protocol was submitted to the Yale institutional review board (#2000035398) and it was determined that our study was exempt from review and approval.

Setting

YNHHS is a northeastern United States health system with 2,681 beds across five acute care hospitals (Bridgeport Hospital, Connecticut; Greenwich Hospital, Connecticut; Westerly Hospital, Rhode Island; Lawrence & Memorial Hospital, Connecticut; Yale New Haven Hospital, Connecticut), and an ambulatory network with greater than 300 sites of care across the states of New York, Connecticut, Massachusetts, and Rhode Island. YNHHS is affiliated with the Yale School of Medicine. The hospitals within the system include Level I trauma hospitals, three teaching hospitals, and three hospitals that are recognized as Magnet facilities by the American Nurses Credentialing Center. The hospitals range in size from a 95-bed community hospital to a 1,567-bed academic medical center (Yale New Haven Health, 2023). The HH performance improvement program includes: i) a system-wide policy declaring the expectations and indications for HH performance by staff in all care settings; ii) HH training for all new staff; iii) annual refresher training for HH; and iv) methods for quality assessment and performance feedback In the hospital and Emergency Department settings, HH performance is primarily assessed using a "secret shopper" model. HH audits are covertly conducted by nursing staff trained to monitor whether HH was practiced by the indications as outlined by the CDC (Glowicz et al., 2023). HH data are input into a unified HH "dashboard" showing unit- and aggregate hospital-level performance, and is available for all staff. Therefore, this system is ideal for testing the implementation of novel HH techniques and protocols. IP specialists, infectious disease clinicians, and hospital leadership were available to provide informed responses to our surveys at different phases of the study.

Phase 1: tabular task analysis for hand hygiene

The vital human perceptions, cognitions, and actions associated with handwashing with soap and water and hand rubbing with ABHS for TTA were determined (Stanton, 2006; Stanton et al., 2017) in Phase 1.

In US hospitals, efforts for quality improvement and patient safety included the adoption of checklists. US hospitals accreditation agencies have also advocated for checklists. For example with insertion of central lines, as a safety intervention, to decrease risk of patient harm and infections (central line associated blood stream infections- CLABSI). Of note, this checklist also includes a step on hand hygiene.

As HCP including IPs frequently use checklists, we identified the need to use a similar HFE tool. Task analyses and checklists are very similar in that they both have specific steps and goals. However, the task analysis tool provides the user further information and opportunity to reflect on challenges, harms, and solutions for each of the steps/ tasks and subtasks.

Detailed work addressing the application of HFE in healthcare has been predominantly accomplished using the Systems Engineering Initiative for Patient Safety (SEIPS) model (Carayon et al., 2006, 2020). The SEIPS model presents a framework that can be used to clarify healthcare structures, processes, outcomes, and their relationships, and this model tends to be implemented at an organizational or macro-level. While we acknowledge there are many existing frameworks and HFE tools such STAMP (Altabbakh et al., 2014; Canham, 2018), FRAM (Patriarca et al., 2020) and SEIPS models, we opted to focus on the task analyses, as it provides the non-HFE healthcare personnel, specific actions of each task, with an opportunity to also identify corresponding challenges, harms and solutions. For our research, select components of the SEIPS model were included, but we chose a very narrow scope in terms of the individual subtasks (steps) of the HH process outlined by the WHO guideline (Fig. 1.). Our work focused on the individual harms associated with each process step, which allowed us to- identify opportunities for improvement.

Participants

To construct the TTA, our team recruited five YNHHS staff members: two human factors engineers and three infectious disease physicians trained in the principles of IP and healthcare epidemiology.

Procedure

The selection of the column headers for task analysis focused on factors that can improve the understanding of procedure and process flow and included task, perception, cognition, action, user needs, challenges, harms, and proposed solutions. *Task* refers to a single unit of action (e.g., each individual step of the HH process), as in the WHO's "How to Handwash?" and "How to Handrub?" posters (World Health Organization, 2009- Fig. 1). *Perception* refers to the initial stimuli within an environment that a user recognizes upon performing that step; for example, when an HCP walks into the room, they need to understand the situation (e.g., what kind of care is needed, where HH supplies are located, and how to deal with the presence of other people in the room). *Cognition* refers to the user's mental processes or decisions based on what they perceive and the knowledge they have regarding the task (e.g., a given HCP's cognition regarding how to perform HH could be related to their training or experience). *Action* describes the specific psychomotor activities the user performs to complete the step (e.g., covering all surfaces of the hands or rubbing hands palm to palm). *User needs* refer to what the user must be able to do to complete an action (e.g., tools, training, knowledge, skill level, or technical competence needed to properly perform HH). *Challenges* refer to the personal, social, technological, or environmental barriers the user must overcome to finish the task; for example, normative social behavior can influence an individual's intent to perform HH. *Harms* refer to any potential risks (microbiological or safety) caused by not performing or incorrectly performing the task or subtask (e.g., incorrectly performing the task can result in HAI transmission). *Proposed solutions* cover potential mitigation or alternative approaches to challenges or harms (e.g., solutions may provide possible options for change that can improve HH quality).

Phase 2: card sorting and tabular task analysis validation and verification by subject matter experts

For phase 2, card sorting, which complements TTA, was performed on the WHO tasks by IP subject matter experts (SMEs) to establish a priority for the various actions and identify the steps that should be prioritized based on the qualitative rankings. Observations conducted by our subject matter experts in the past highlighted concerns regarding compliance with HH technique (Fig. 1). IP SMEs performed criticality analysis with validation (i.e., Are we focusing on the right things?) and verification (i.e., Do we have the steps correct?) with an emphasis on HH training gaps and potential harms to HCP (U.S. Department of Health and Human Services, 2016). This validation and verification helped improve our TTA and prioritize the steps that are important to prevent HAIs but are frequently missed. This mixed approach of card sorting and TTA validation and verification allowed us to focus quantitatively and qualitatively on the most important aspects of the HH process, and to identify the best areas of focus that can reduce HAI prevalence based on multiple sources of information.

Participants

The card-sorting task and validation and verification process was completed by 10 IP SMEs IP specialists have various roles across hospital settings, such as performing active monitoring and coaching of HH quality for frontline HCP; surveillance and mitigation efforts for HAIs, and frequent collaboration with frontline healthcare workers and hospital leadership regarding education and feedback on IP behaviors by HCP, with the goal of improving our understanding of how to optimize HH and thus reduce HAI prevalence. The 10 IP specialists had 56

combined years of experience as IP specialists (mean, 5.6 years), 96 combined years of experience in clinical microbiology laboratories (mean, 19.2 years), and 64 combined years of experience in nursing (mean, 16 years).

Materials

The card-sorting task was conducted using Miro online collaboration software (Miro, 2023). Each card in the card-sorting task represented a step from the WHO's "How to Hand Wash?" and "How to Hand Rub?" posters (World Health Organization, 2009).

Procedure

Our card-sorting method was adapted from that of Stuster (2019). This technique allows participants to rank the WHO guidelines steps on the three distinct parameters: importance, frequency, and criticality. Card sorting was performed separately for "How to Hand Wash?" and "How to Hand Rub?" HH protocols. Because the overall task (i.e., HH) was associated with several different subtasks, the SMEs were instructed to compare subtasks (which we hereafter refer to as steps) to identify the perceived areas of most concern (e.g., steps with the highest likelihood for transmitting HAIs if inadequately performed).

Under observation by one of the study's HFE researchers, each participant completed the card-sorting task. The researcher explained that the purpose of the card sort was to help determine both prioritization and frequency of occurrence of the WHO steps. The participants could view the WHO posters at any time if they needed clarification on a step or the associated image.

The participants were asked to first group the steps into one of three categories: more important, important, and less important (Fig. 2). They had to use at least two of the three categories to ensure that everything was not categorized as more important. Following categorization, participants ranked most important to least important within each category, where importance referred to the importance of an individual step relative to the other steps in preventing HAIs.

Next, the participant performed the same task for frequency, which described how often they saw a particular step done and whether the step was performed correctly. The participants were instructed to consider each step individually based on what they had observed in their professional careers. They categorized the steps into more frequent, frequent, and less frequent, and then ranked each step within each category.

A numerical criticality value was calculated for each card based on the respective card's importance and frequency, as described by Stuster (2019). The criticality value for each step reported by each participant was calculated by adding the importance and frequency. The average criticality values ($M_{\text{criticality}}$) and standard deviation for each step were subsequently calculated across all 10 participant rankings for each HH protocol. This numerical value provides insight into how a specific task is viewed across multiple dimensions by the IP SMEs. In our study, the smallest numerical criticality values were ranked as higher criticality because lower numbers corresponded to higher importance and lower frequency.

Once the card sorting was complete, the SMEs helped review the TTA and provided qualitative feedback, which we referred to as TTA validation and verification. They described areas that needed improvement, defined in greater detail the potential harms of not performing a specific action from an IP perspective, and provided insight into the assumptions made in the initial construction of the TTA. Additionally, the SMEs noted that ABHS is the primary method of HH implemented in hospital settings. Therefore, we updated the TTA based on the SMEs' feedback and only proceeded with ABHS.

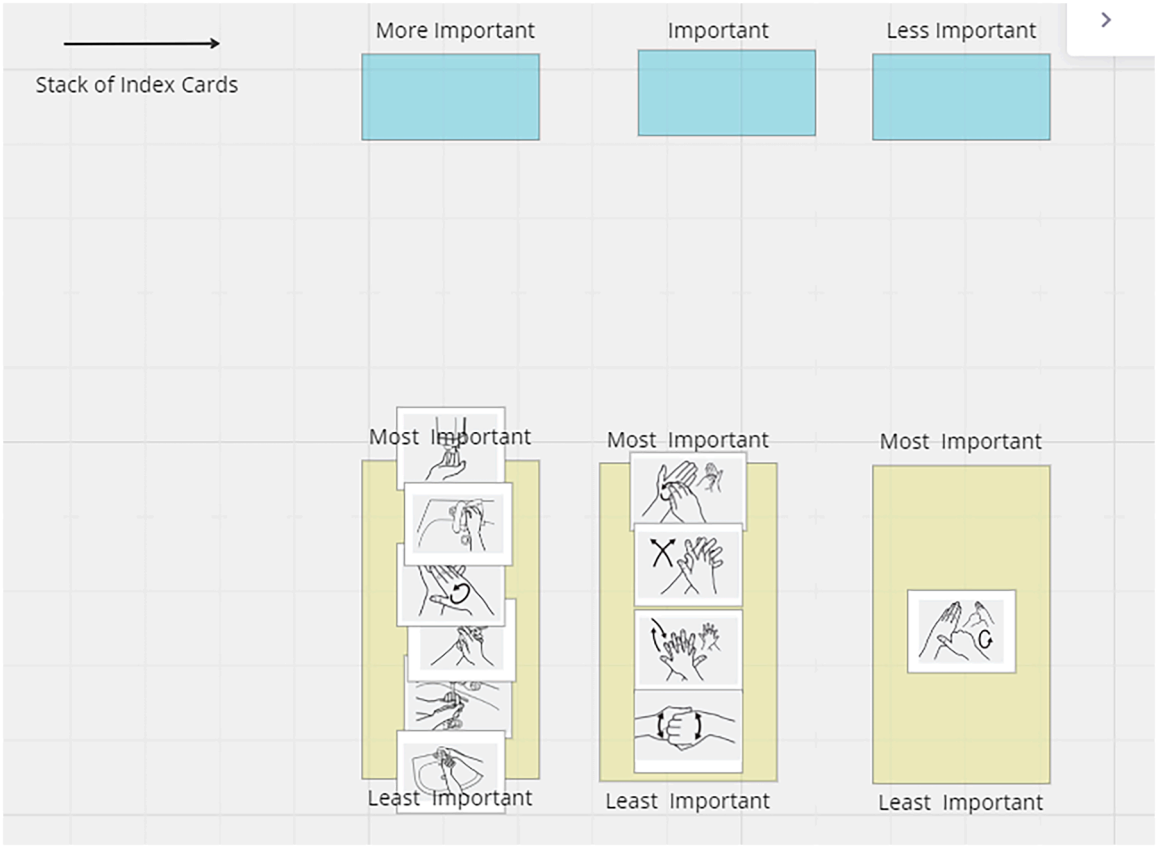

Fig. 2. An example of importance ranking by card sorting of all steps in each hand hygiene protocol (i.e., "How to Hand Wash?" and "How to Hand Rub?") using Miro. Participants were instructed to click and drag the card to the appropriate pile based on the importance from the perspective of an infection preventionist.

Phase 3: tabular task analysis validation and verification with hospital leadership

We presented our findings from phases 1 and 2 to members of the YNNHS hospital physician and nursing leadership, each of whom have opportunities to perform HH in their practices. Individual interviews were performed to familiarize hospital leadership with how HFE can be used to improve the HH process. Through these interviews we were able to learn their perspectives about appropriate levels of detail and dissemination strategies for the information contained in the TTA, learn their personal experiences related to HH and their staff, and establish the next steps for working with their organizations to pursue a new HH quality initiative.

Participants

Twenty executive-level hospital leaders were interviewed to validate and verify our proposed implementation of HFE procedures for improving HH quality. Their roles included Chief -Medical Officers or assistant Chief Medical Officers as well as Chief Nursing Officers and other nursing executive leaders for individual campuses and service lines.

Materials

Our team members provided hospital leadership with a Microsoft PowerPoint (Microsoft Corporation, Redmond, WA, USA) slide deck that described the HH task analysis and an anonymous follow-up survey on the individual's perception of the usefulness of the task analysis. The questions were adapted from Karamchandani et al. (2021) (Appendix A) and scored using a 5-point Likert scale.

Procedure

Each hospital leader first participated in an online meeting with a facilitator (i.e., a member of our team), and the participant was introduced to the overall purpose of the study. The participant was then guided through a PowerPoint presentation on the role of HFE in HH, the collaboration with IP specialists, and the HH TTA work we conducted with an abridged focus on user needs, challenges, harms, and solutions. The participant was able to provide feedback during the interview session, as well as anonymously respond to the survey questions at the end, or both. Surveys were conducted through the Yale Qualtrics Survey Tool (https://your.yale.edu/yale-link/Qualtrics-survey-tool).

Results

Phase 1: tabular task analysis for hand hygiene

The results of the initial TTA constructed by HFE personnel and IP specialists for handwashing with soap and water and hand rubbing with ABHS is shown in Table 1.

Phase 2: card sorting and tabular task analysis validation and verification by subject matter experts

Card sorting

For handwashing with soap and water, the average criticality values (calculated by adding importance and frequency) ranged from 8.60 (*SD* = 4.22) for the perceived most critical step, "rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa," to 16.10 (*SD* = 3.81) for the perceived least critical step, "rinse hands with water" (Table 2).

For hand rubbing with ABHS, the average criticality values ranged from 7.30 (*SD* = 3.13) for the perceived most critical step, "once dry, your hands are safe," to 10.30 (*SD* = 2.67) for the perceived least critical step, "rub hands palm to palm" (Table 3). However, overall, the criticality values for ABHS were very similar and had overlapping standard deviations.

Tabular task analysis verification

When discussing the TTA with participants, there was some feedback that stood out as exceptionally important for TTA construction and refinement. For example, several SMEs discussed the vocabulary barrier when understanding appropriate perceptions of WHO steps. In particular, the dorsum, which is the back of the hands, was an area of concern, and it was suggested that some individuals who are not IP specialists may not be familiar with this term.

There was also concern about the final step of the WHO's hand wash and hand rub guidance, which describes the concept of the hands now being "safe" with a picture of two hands facing upward. As one participant remarked, "This step does not explain any particular action associated with this picture, and people may think that rubbing is not necessary."

For cognition, a common theme discussed and supported by multiple SMEs was applying the proper volume of HH products, which may vary by person and product used. To successfully perform HH, the action column of the TTA included appropriate actions to cover the surface area. However, because this is a psychomotor task, the SMEs focused on the training and instruction of proper technique. They mentioned that HH technique training is a vital component for each step of the process, and there appear to be large gaps in the intricacies of performing this technique, such as the amount of pressure and friction used.

During the discussion of challenges, SMEs raised several environmental considerations. They described broken sinks and dispensers, improper dispensing amounts for adequate compliance with the manufacturer's guidelines, and distractions caused by malfunctioning technology. One SME noted, "The automatic faucet would not shut off. I began to try and figure out how to fix it, and in the process, I touched contaminated surfaces, forgetting about HH."

The harms column included the most areas for potential intervention. The feedback that focused on the HH environment included the contamination of faucet controls owing to multiple users of the same faucet and bacteria that were present on the sink itself. The feedback for harms related to insufficiently performing HH steps were related to the necessity of having enough product to cover all hand surfaces and ensuring that the product was either sufficiently dry (in the case of ABHS) or completely removed (in the case of soap) to minimize bacterial load. Technique-specific concerns covered missing areas of the hands during HH, such as the thumbs, fingernail beds, nails, and finger webbing. The TTA that was produced following the feedback from the SMEs is shown in Table 4.

A unique challenge introduced by the SMEs was how the HH methods could be employed by someone with limb differences, as many of the steps outlined in the WHO HH steps can only be completed using both hands. However, this was not incorporated in our revised TTA, as it was beyond the scope of our study.

Phase 3: Validation and Verification with Hospital Leadership

Overall, the hospital leaders in the present study strongly agreed with our survey questions (n = 15). The respondents to the anonymous survey found that i) our TTA was useful for learning the individual steps and the possible challenges and solutions, ii) that our TTA was easy to use, iii) that our TTA should be used for training all HCP, and iv) that TTA could be easily applied to other safety-oriented patient care activities (Table 5).

Among the qualitative feedback from hospital physician leadership, several noted a tendency for HCP to perform actions in a manner similar to others around them. Furthermore, most stated that HH should be considered as important other organizational pillars in healthcare such as teamwork, leadership, and safety. Several hospital physician leaders also stated that this approach could potentially be applied to other patient care activities, although the suggested activities varied (e.g., changing a dressing, inserting a vascular access device, or design of the built environment).

Table 1
Results of the tabular task analysis (TTA) constructed by HFE personnel and IP specialists for handwashing with soap and water and hand rubbing with alcohol-based hand sanitizer (ABHS). The Initial TTA included a task and subtask structure for the hand hygiene (HH) steps for the WHO guidelines, exemplified by the slogan "My 5 Moments for Hand Hygiene" for healthcare settings (subtask 1.1a–e), and initial perceptions, cognitions and actions that HCPs had to perform. User needs, challenges, and solutions had not been previously defined.

Task	Subtask	Perception	Cognition	Action	User Needs	Challenges	Proposed Solutions
1.0: Start hand hygiene	1.1a: Scenario - entering patient room	Identify hand hygiene product / station	Understand need to wash hands	Start hand hygiene	… have time for hand hygiene.	Provider may be rushed attending patient (e.g., code event).	
	1.1b: Scenario - leaving patient room	Identify hand hygiene product / station	Understand need to wash hands	Start hand hygiene			
	1.1c: Scenario - before donning PPE	Identify hand hygiene product / station	Understand need to wash hands	Start hand hygiene			
	1.1d: Scenario - after donning PPE	Identify hand hygiene product / station	Understand need to wash hands	Start hand hygiene			
	1.1e: Scenario - after contaminant event	Identify hand hygiene product / station	Understand need to wash hands	Start hand hygiene			
2.0: Select appropriate hand hygiene technique	2.1: Check hands	Perceive if hands are visibly soiled	Understand use of different types of products	Select appropriate hand hygiene technique	… understand uses for different products; … have access to appropriate product.	User does not know which product to use; User does not have appropriate product readily available.	Include "just in time" education at wash stations; Ensure wash stations have both products available.
3.0: Rub hands	3.1: Apply palmful of the product in a cupped hand, covering all surfaces	Identify hand hygiene product	Understand how much product to use; Understand how to operate dispenser	Dispense product into hand	… understand how much product is needed.	User does not dispense sufficient product.	
	3.2: Rub hands palm to palm	Identify palms	Understand how to position hands	Place palms against each other; Rub hands palm to palm in a circular pattern.	… position hands correctly.	User misses parts of hands intended by this subtask.	
	3.3: Right palm over left dorsum with interlaced fingers and vice versa.	Identify palms; Identify dorsa; Identify fingers	Understand how to position hands	Place palm over dorsum and interlace fingers; Rub palm up and down over dorsum; Repeat for opposite hands.	… position hands correctly. … complete action for both hands. … identify dorsum.		
	3.4: Palm to palm with fingers interlaced	Identify palms; Identify fingers	Understand how to position hands	Place palms against each other with interlaced fingers; Rub palms together up and down.	… position hands correctly.	User misses parts of hands intended by this subtask.	
	3.5: Back of fingers to opposing palms with fingers interlocked	Identify palms; Identify fingers	Understand how to position hands	Place fingers against palms and interlock fingers; Move hands side-to-side.	… position hands correctly.	User misses parts of hands intended by this subtask.	
	3.6: Rotational rubbing of left thumb clasped in right palm and vice versa	Identify palms; Identify thumbs	Understand how to position hands	Grab thumb with opposite hand; Rotate hand back and forth; Repeat for opposite hands.	… position hands correctly. … complete action for both hands.	User misses parts of hands intended by this subtask; User does not repeat for second hand.	
	3.7: Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa	Identify palms; Identify fingers	Understand how to position hands	Clasp fingers together and place in opposite palm; Rub fingers in	… position hands correctly. … complete action for both hands.	User misses parts of hands intended by this subtask; User does not repeat for second hand.	

(*continued on next page*)

Table 1 (*continued*)

Task	Subtask	Perception	Cognition	Action	User Needs	Challenges	Proposed Solutions
				palm; Repeat for opposite hands.			
	3.8: Rub hands together until they are dry	Identify any residue	Understand when hands are dry	Wait for hands to dry.	… wait for hands to dry.	User may be rushed and not have time to wait on hands; User may not realize hands have not completely dried.	
4.0: Wash hands	4.1: Wet hands with water	Identify faucet controls	Understand how to operate faucet; Understand where to position hands	Activate sink; Move hands under water.	… wet hands with sufficient water.	User may not wet enough surfaces of hands.	
	4.2: Apply enough soap to cover all hand surfaces	Identify hand hygiene product	Understand how much product to use; Understand how to operate dispenser	Remove hands from water; Dispense product into hand.	… understand how much product is needed.	User does not dispense sufficient product.	
	4.3: Rub hands palm to palm	Identify palms	Understand how to position hands	Place palms against each other; Rub hands palm to palm in a circular pattern.	… position hands correctly.	User misses parts of hands intended by this subtask.	
	4.4: Right palm over left dorsum with interlaced fingers and vice versa.	Identify palms; Identify dorsa; Identify fingers	Understand how to position hands	Place palm over dorsum and interlace fingers. Rub palm up and down over dorsum Repeat for opposite hands.	… position hands correctly. … complete action for both hands. … identify dorsum.	User misses parts of hands intended by this subtask User does not repeat for second hand Lay user does not know what a "dorsum" is.	
	4.5: Palm to palm with fingers interlaced	Identify palms; Identify fingers	Understand how to position hands	Place palms against each other with interlaced fingers; Rub palms together up and down	… position hands correctly.	User misses parts of hands intended by this subtask.	
	4.6: Back of fingers to opposing palms with fingers interlocked	Identify palms; Identify fingers	Understand how to position hands	Place fingers against palms and interlock fingers; Move hands side-to-side.	… position hands correctly.	User misses parts of hands intended by this subtask.	
	4.7: Rotational rubbing of left thumb clasped in right palm and vice versa	Identify palms; Identify thumbs	Understand how to position hands	Grab thumb with opposite hand; Rotate hand back and forth; Repeat for opposite hands.	… position hands correctly. … complete action for both hands.	User misses parts of hands intended by this subtask. User does not repeat for second hand.	
	4.8: Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa	Identify palms; Identify fingers	Understand how to position hands	Clasp fingers together and place in opposite palm; Rub fingers in palm; Repeat for opposite hands.	… position hands correctly. … complete action for both hands.	User misses parts of hands intended by this subtask. User does not repeat for second hand.	
	4.9: Rinse hands with water	Identify soap suds on hands	Understand how to rinse hands	Move hands under water so all soap is washed off.	… wash off all soap and other material.	User does not wash all surfaces and leaves material behind.	
	4.10: Dry hands thoroughly with a single use towel	Identify paper towel; Identify wet hands	Understand how to operate paper towel dispenser	Acquire paper towel Rub paper towel over hands.	… access a clean towel without contamination.	User contaminates clean hands while grabbing towel.	Use reliable automated paper towel dispensers.
	4.11: Use towel to turn off faucet	Identify faucet controls	Understand how to position paper towel to avoid contacting faucet	Use paper towel to turn off faucet.	… operate sink with towel covering metal.	User is unable to maintain towel shielding while operating mechanism.	Use simple on/off mechanisms such as lever faucets instead of twist faucets.

Table 2
Average criticality values ($M_{criticality}$) and standard deviations (SD) for WHO steps for handwashing with soap and water. The criticality value for each step reported by each participant was calculated by adding the importance and frequency.

Step	$M_{criticality}$	SD
Wet hands with water	15.30	4.11
Apply enough soap to cover all hand surfaces	13.10	3.81
Rub hands palm to palm	12.10	2.18
Right palm over left dorsum with interlaced fingers and vice versa	10.00	2.45
Palm to palm with fingers interlaced	11.10	3.11
Backs of fingers to opposing palms with fingers interlocked	10.00	2.67
Rotational rubbing of left thumb clasped in right palm and vice versa	9.70	3.02
Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa	8.60	4.22
Rinse hands with water	16.10	3.81
Dry hands thoroughly with a single use towel	14.90	3.41
Use towel to turn off faucet	11.10	1.97

Table 3
Average criticality values ($M_{criticality}$) and standard deviations (SD) for WHO steps for hand rubbing with ABHS.

Step	$M_{criticality}$	SD
Apply a palmful of the product in a cupped hand, covering all surfaces	9.10	1.52
Rub hands palm to palm	10.30	2.67
Right palm over left dorsum with interlaced fingers and vice versa	9.90	1.85
Palm to palm with fingers interlaced	9.90	2.18
Backs of fingers to opposing palms with fingers interlocked	8.90	1.45
Rotational rubbing of left thumb clasped in right palm and vice versa	8.80	2.15
Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa	7.80	1.48
Once dry, your hands are safe	7.30	3.13

Discussion

To the best of our knowledge, this is the first study to use TTA to improve HH quality for hospital settings. Our results suggest that our integrative HFE-based approach may help to increase HH quality for HCP in hospital settings by improving HH guidelines and consequently reduce the incidence of HAIs. Our work highlights how TTAs can be used to critically assess the steps for completing HH as recommended by the WHO (World Health Organization, 2009), and the potential applicability of this approach to other patient care-related activities.

In the first phase, TTA construction, the HFE personnel focused on the interactions between the human and the environment (i.e., perception, cognition, and action), whereas the IP specialists focused on user needs, challenges, harms, and solutions associated with HH. We found that the unique knowledge and perspective of HFE personnel and IP specialists contributed to building a comprehensive TTA.

The second phase of our study allowed us to focus on the specific HH steps that are of high importance but are frequently either not performed or not performed correctly. Card sorting helped us successfully prioritize the HH steps that are perceived to be most important and can be used to highlight the critical steps that are missed during the busy workflow of HCP. Our results indicated that attaining high-quality HH should include methods to ensure the thumbs, back of hands, and fingernails are included in hand rubbing with ABHS. However, the criticality values for the ABHS steps in the present study were very similar (Tables 2 and 3), which may be a result of the lack of specificity of the methodology or the inability of the SMEs to prioritize one step over another. Additionally, while the WHO guidance for ABHS indicates that hand rubbing should occur for 20–30 seconds, evidence suggests that rubbing hands together for at least 15 is as important, or possibly more important, than coverage issues (e.g., backs of hands) for antimicrobial efficacy. Furthermore, although there is evidence that dry time is a major driver of antimicrobial efficacy, and there is little correlation between hand surface area and antimicrobial efficacy (Boyce, 2023; Suchomel et al., 2018), existing visual aids are not clear about the importance of complete drying. Therefore, the duration of hand rubbing is something that should be considered in future TTAs and may yield different criticality values.

The initial validation and verification of the TTA with SMEs yielded several findings that HFE personnel used to further define our focus areas. To successfully perform HH, it was emphasized that the action column of the TTA needs to include appropriate actions to cover the surface area of the hands. Additionally, the SMEs noted the importance of training and instruction of proper technique because HH is a consciously controlled activity. It is widely accepted that specialized training exists for surgical scrub techniques and that every employee must annually receive HH instruction. However, clarification is needed regarding intricacies of performing this technique, as our SMEs reported variation exhibited by HCP, including in the amount of pressure and friction that is used. The SMEs also mentioned that HH technique training is vital for each step of the process. This is consistent with previous studies that demonstrated the importance of focused training to improve HH practices of HCP (Singh & Barnard, 2023; Stone, 2018).

Several SMEs discussed a barrier to vocabulary when understanding appropriate perceptions of WHO steps. For example, the dorsum (i.e., the back of the hands) was an area of concern, as some individuals who do not work in IP may not be familiar with this term. There was also concern regarding the final step of the WHO's guidance, which describes the concept of the hands being "safe" once dry with a picture of two hands facing upward. As the message of the image is slightly unclear, individuals using ABHS may not think rubbing is necessary until hands are dry. Therefore, it is necessary to consider how likely HCP are to appropriately interpret and understand terminology when constructing TTAs. Furthermore, the SMEs emphasized the importance of the volume of product that is used; this has been previously emphasized, as different products and hand sizes could require different amounts of product (Boyce, 2019, 2021; Glowicz et al., 2023). However, automated dispensers can reduce the potential for receiving an inadequate amount of product (Boyce, 2023; Roth et al., 2018), and thus educating HCP on the importance of stopping to obtain the fully dispensed amount of product.

During the discussion of challenges, SMEs also noted that several environmental issues should be taken into consideration, such as sinks and dispensers breaking, dispensing of appropriate volumes of product, and distractions caused by HH technology not working correctly. Concerns surrounding issues with the built environment in hospital settings have long been a concern in proper HH implementation (Boyce, 2023; Ellingson et al., 2014; Glowicz et al., 2023), and our SMEs identified some specific ways that HCP may be affected. For example, one SME reported that the automatic faucet they were using would not shut off, and in trying to fix it, they forgot about HH, and touched contaminated surfaces. Furthermore, potential harms included the contamination of faucet controls owing to factors such as i) multiple users of the same faucet and bacteria that were present on the sink itself, ii) the necessity of having enough product to cover all surfaces, and iii) ensuring that the product was either sufficiently dry (in the case of ABHS) or completely removed (in the case of soap) to minimize bacterial load. Technique-specific challenges that were raised included covering commonly missed areas of the hands during HH, such as the thumbs, fingernail beds, nails, and finger webbing.

Our interviews with physician and nursing leaders revealed they felt HH is critical to safety, that its importance should be elevated in hospital settings, and that TTAs could be applied to other patient-centered activities (such as cleaning a dressing and inserting a port). However, they also noted that HCP HH quality appeared to be related to the HCP observations of what other HCP are doing, which supports the maintenance of perceived subjective norms associated with HH. Their insights

Table 4
Final end product of the alcohol-based hand sanitizer (ABHS) tabular task analysis (TTA) following revision from subject matter expert (SME) feedback.

Task	Perception	Cognition	Action	User Needs (HCP must be able to...)	Challenges	Harms	Proposed Solutions
1.0. Apply palmful of the product in a cupped hand, covering all surfaces	Identify hand hygiene product	Understand how much product to use; Understand how to operate dispenser	Dispense product into hand	… understand how much product is needed.	User does not dispense sufficient product	Inadequate HH can lead to transmission of pathogens to other patients and HCP/ environments…. Inadequate amount will not decontaminate appropriately…. Drive-by dispensing (passing hands under a dispenser when entering a room vs. stopping and pausing at it to get the full dispensed amount) also has an environmental impact, as the excess not captured by the hand can run down the walls and land on the floor which damages surfaces	Have automated dispensers, with precise amount dispensed... HCP are trained to obtain the correct amount in their hands and not do drive-by dispensing... May need to also consider adding some training on impact on the environment if the product spills frequently
2.0. Rub hands palm to palm	Identify palms	Understand how to position hands	Place palms against each other; Rub hands palm to palm in a circular pattern	… position hands correctly.	User misses parts of hands intended by this subtask	Inadequate HH can lead to transmission of pathogens to other patients and HCP/ environments... Users are at risk of missing part of palm near to thumb, leads to not fully clean hand... There is perception that if you clean the palms of your hands by rubbing them together your fingers will be doing the same action... There is perception that just cleaning the palms is enough to perform a proper hand hygiene	HCP trained on covering the hand surfaces… HCP trained well in hand hygiene techniques... If situational, and HCP has objects in one hand, precluding full HH, then HCP are trained to place object in safe location to free up both hands, and complete all the steps of HH... HCP are provided with a supporting structure if only one hand is permanent scenario, for scrubbing the palm
3.0. Right palm over left dorsum with interlaced fingers and vice versa.	Identify palms; Identify dorsum; Identify fingers	Understand how to position hands	Place palm over dorsum and interlace fingers; Rub palm up and down over dorsum; Repeat for opposite hands	… position hands correctly. … complete action for both hands. … identify dorsum.	User doesn't understand this step or misses this step... Lay user does not know what a "dorsum" is... HCP may not have two hands to perform this specific task... Washing dorsal surfaces of hands is not seen as high priority for washing compared to palms/fingers	Inadequate HH can lead to transmission of pathogens to other patients and HCP/ environments... Also, part of the webbing between fingers is often missed, an area where bacteria can "hide"… If step is not done, potential pathogens will hide in the area, contaminating the rest of the surfaces	HCP trained on covering the hand surfaces… HCP trained well in hand hygiene techniques... If situational, and HCP have objects in one hand, precluding full HH, then HCP are trained to place object in safe location to free up both hands, and complete all the steps of HH... HCP trained on importance of washing dorsal surfaces of hands
4.0. Palm to palm with fingers interlaced	Identify palms; Identify fingers	Understand how to position hands	Place palms against each other with interlaced fingers; Rub palms together up and down	… position hands correctly.	User misses parts of hands intended by this task… User doesn't follow all the way down to finger webbing	Missing this step may lead to inadequate hand hygiene of the finger spaces, and lead to transmission of microbes... Could also miss the top side of fingers and nail beds leading to higher bacterial counts after hand hygiene of hands... increased risk of direct/indirect transmission	HCP trained on covering the hand surfaces… HCP trained well in hand hygiene techniques… HCP trained to free up hands, if carrying objects e.g. cellphones, to complete the hand hygiene process
5.0. Back of fingers to opposing palms with fingers interlocked	Identify palms; Identify fingers	Understand how to position hands	Place fingers against palms and interlock fingers; Move hands side-to-side	… position hands correctly.	User misses parts of hands intended by this subtask… This is not a well-known step for staff outside of an OR setting	Missing this step may lead to inadequate hand hygiene, and lead to transmission of microbes… user may not clean to the tips of the fingers missing the fingernails	HCP trained on covering the hand surfaces… HCP trained well in hand hygiene techniques
6.0. Rotational rubbing of left thumb clasped in right palm and vice versa	Identify palms; Identify thumbs	Understand how to position hands	Grab thumb with opposite hand Rotate hand back and forth Repeat for opposite hands	… position hands correctly. … complete action for both hands.	User misses parts of hands intended by this subtask; User does not repeat for second hand	User misses the tip of the thumb, Nail bed and under nail... Missing this step of cleaning the thumbs may lead to inadvertent transmission of microbes... User may not fully wrap hand around thumb for full coverage... User may not get	HCP trained on covering the hand surfaces… HCP trained well in hand hygiene techniques

(*continued on next page*)

Table 4 (*continued*)

Task	Perception	Cognition	Action	User Needs (HCP must be able to...)	Challenges	Harms	Proposed Solutions
						tips of thumbs, under nails and nail beds... Very important step as we use the thumb for everything and we usually forget to clean it; it can harbor pathogens and cross contaminate the rest of the surfaces	
7.0. Rotational rubbing, backwards and forwards with clasped fingers of right hand in left palm and vice versa	Identify palms; Identify fingers	Understand how to position hands	Clasp fingers together and place in opposite palm; Rub fingers in palm Repeat for opposite hands	… position hands correctly. … complete action for both hands.	User misses parts of hands intended by this subtask User does not repeat for second hand	Missing this step of cleaning the clasped hands may lead to inadvertent transmission of microbes... Different users may apply varying amount of pressure while rubbing... Hand washing is the physical removal of dirt and bacteria so this may lead to low level of cleaning	HCP trained on covering the hand surfaces… HCP trained well in hand hygiene techniques
8.0. Once dry, your hands are safe	Identify any residue	Understand when hands are dry	Continue rubbing hands until dry	… wait for hands to dry.	User may be rushed and not have time to wait for hands to dry; user may not realize hands have not completely dried	Incomplete drying may lead to inadequate disinfection; or if wipes used to dry off the alcohol, then inadequate disinfection	HCP trained on covering the hand surfaces… HCP trained well in hand hygiene techniques… HCP is trained to dry hands by continuously rubbing hands together and not to flap hands in air to air dry, or use a towel to dry off the ABHS product

Table 5
Responses from the hospital physician leadership survey (n= 8), and nursing (n= 7) scored on a 5-point Likert scale.

	Physician (n=8)		Nurse (n=7)	
Question	*M*	*SD*	*M*	*SD*
The Task Analysis was useful to learn the individual steps for this patient activity.	4.25	0.43	4.26	0.95
The Task Analysis was useful to learn the possible challenges for the completion of this patient activity.	4.38	0.48	4.14	0.90
The Task Analysis helped me understand the potential solutions to challenges for completing the patient care activity.	4.63	0.48	4.43	0.54
The Task Analysis was easy to use.	4.63	0.99	4.57	1.13
The Task Analysis needs to be used for training all HCP in the patient care activity.	4.75	0.43	4.71	0.49
I need more Task Analyses for completing patient care activities safely.	4.75	0.43	4.57	0.54

1 = strongly disagree, 5 = strongly agree

will be useful for future implementation of TTAs, such as for the development and dissemination of an HH initiative across hospital settings., The support and engagement of hospital leadership will allow us to address the barriers to HFE at the highest level and tailor developed approaches to improving HH quality in hospital settings.

Given the promising feedback from our hospital leadership and the widespread use of checklists in healthcare settings, we propose that HCP can be trained to use TTAs to help them better understand HH steps. However, unlike checklists, TTAs identify possible barriers or challenges, including within the healthcare environment, as well as solutions (Stanton, 2006; Stanton et al., 2017; Catchpole et al., 2021). Furthermore, using a TTA to break down a common task into its subtasks could better inform HCP of the complexity of common and frequent safety measures for patient care such as HH, personal protective equipment donning and doffing, and fingerstick glucose testing. TTA use can encourage HCP to work on the early identification of the challenges and barriers, and assist with systems improvement in finding solutions for their hospital or environment. Furthermore, TTAs can provide insights into possible short- and long-term harms of barriers and potentially decrease variability in the built environment of the healthcare facility. We propose that adopting TTAs will decrease errors when performing tasks, especially for common patient care tasks such as HH.

In addition to the development of detailed guidelines, there is value in producing more effective user-centered, patient-focused messaging such as posters and other visual guides that are strategically placed and easily seen by HCP to improve HH quality (Gázquez-López et al., 2021; Jenner et al., 2005). We propose that future HH initiatives should include developing novel posters focused on the specific lessons learned from this research. Fig. 3 shows a proof-of-concept design to complement existing visual guides that will, upon completion, encourage HCP to more accurately comply with HH steps, thereby improving HH quality and decreasing the incidence of HAIs. Validation should be performed in the future to determine if HCP achieve a minimum level of competency in proper HH technique using more informative posters and infographics.

Although TTAs show promise for other patient-centered activities, there are factors that may hinder the initial development and subsequent dissemination of TTAs across hospital settings. For example, the development of a TTA can be time consuming and inconvenient, and there will be an initial upfront effort requiring dedicated time to educate HCP on the implementation of new concepts via TTAs. HCP are already extremely busy and suffer from high rates of work overload and burnout (e.g., Lluch et al., 2022; Rotenstein et al., 2023). Therefore, HCP may be initially inconvenienced as they learn this HFE-based approach to improving patient care and safety. This may lead to HCP not finding an initial benefit as this process may extend their work hours if training is done after hours or outside of direct patient care. Our SMEs also noted a potential issue with how the current WHO HH steps could be employed by HCP with limb differences. Because many of the steps require using both hands, there is a need to consider how modifications can be made to WHO steps so they can be adequately performed by individuals with limb differences (e.g., missing a hand, non-functional hand due to injury

Fig. 3. Concept art for an HH initiative focused on areas missed to complement existing visual guides for HCP in hospital settings.

or the presence of a brace, cast, dressing or other material which cannot be removed).

Additionally, our current work was conducted with infectious disease physicians further trained in infection prevention and IP specialists who are SMEs that work on HAI prevention. Because HH is fundamental to preventing HAIs, SMEs have an in-depth understanding of HH importance and the challenges for effective HH. However, our group of SMEs may have a significantly different perspective on HH from other frontline HCP who may not be working in the field of IP. Some might argue that most IP specialists are knowledgeable about HH, but they may not be SMEs on issues related to HH, such as built environment-related issues that could hinder the ability of HCP to perform adequate HH. For example, sinks are often inconveniently placed, dispensers may not be accessible and visible (e.g., Cure & Van Enk, 2015; Ellingson et al., 2014), and putting both types of HH products (ABHS and soap) at the same location is generally not recommended because it is possible for HCP to be confused if dispensers or products appear similar and are located next to each other. This may result in some frontline HCP questioning the value of constructed TTAs.

Although further work is needed to optimize TTA development and implementation in healthcare settings, our current work indicates that our proposed HFE-based approach may ultimately help reduce HAI rates by preventing microbial transfer from the hands of HCP to patients and the environment. To determine if our integrative HFE-based approach can help reduce HAI rates by improving the quality of HH performed by HCP, microbial assessments should be conducted. For example, the

residual microbial burden should be determined on the hands of HCP after completion of HH as usual or following three- or six-step hand rub techniques (Tschudin-Sutter et al., 2017, 2019).

Limitations

One limitation our study faces is the possible introduction of bias in the design of the questions in the leadership survey. These questions were not previously validated. This study was conducted in the context of a single health care-system. However, this system encompasses a large teaching hospital, smaller teaching hospitals, and community hospitals. Another limitation was our interviews were only conducted with physician and nursing leadership and interviews with frontline healthcare staff were not conducted during this study. Future investigation should look at readiness of change of frontline staff towards HH quality and technique training. Our results showed physician and nursing leadership's clear readiness for change.

Conclusions

Our three-phase HFE-based approach to optimize HH quality by HCP revealed the complexity of one of the most basic patient care activities in healthcare settings. Through TTA development, a card-sorting task, and discussion with SMEs, we determined that some of the HH steps were considered more critical than others because they were perceived as highly important but had a lower frequency of completion by HCP. The responses received from hospital leadership indicated that it would be possible to train HCP on appropriate HH techniques using our proposed HH TTA, and TTAs could potentially be developed for other patient care activities. These HFE-based efforts can help improve HH quality by providing specific guidance to HCP, provide a foundation for understanding HH process optimization, and ultimately help reduce HAIs and improve patient safety.

Implications and applications

This study revealed that TTAs and card-sorting tasks, which are HFE-based techniques, show promise for improving HH quality by HCP. Furthermore, it was deemed feasible by hospital leadership to incorporate TTAs in a hospital setting. Our findings may be useful for starting an HH initiative to provide guidance and materials to the healthcare community, which may help improve HH quality and consequently reduce the prevalence of HAIs. Furthermore, this integrative HFE-based approach may help improve HH quality by HCP and could be applied to optimize processes associated with other patient care activities.

Impact statement

HAI prevalence is known to decrease when HH is properly performed by HCP. However, HCP HH quality is not emphasized. This study proposed an integrative, HFE-based approach using TTAs, card sorting, and criticality analyses that can be implemented in hospital settings to improve HH quality and reduce HAIs. This approach can be used to provide guidance and materials to HCP, with the goal of improving HH quality, thereby reducing HAI rates and improving patient safety in hospital settings. This approach can also potentially be applied to other patient care-related processes.

CRediT authorship contribution statement

Michael W. Boyce: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft, Writing – review & editing, Validation. **Trini A. Mathew:** Conceptualization, Data curation, Formal analysis, Methodology, Project administration, Writing – original draft, Writing – review & editing. **Scott C. Roberts:** Conceptualization, Investigation, Methodology, Writing – original draft, Writing – review & editing. **Michael Aniskiewicz:** Project administration, Validation, Writing – original draft. **Kathy Krechevsky:** Conceptualization, Validation, Writing – original draft. **Suzanne Dahlberg:** Conceptualization, Validation, Writing – original draft. **Noelle Frye:** Project administration, Resources, Writing – original draft. **Jamie E. Trumpler:** Project administration, Resources, Writing – original draft. **Leigh V. Evans:** Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft. **Richard A. Martinello:** Funding acquisition, Investigation, Methodology, Project administration, Resources, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

Trini A. Mathew reports other financial grant support was provided by Wayne State University, the Michigan Department of Health and Human Services, and the Infectious Diseases Society of America. Trini A. Mathew reports relationships with GE Healthcare and Google LLC that include equity or stocks. Trini A. Mathew is the Medical Director of Infection Prevention and Control and Antimicrobial Stewardship at Corewell Health (Taylor, MI, USA); is a volunteer member of the Society for Healthcare Epidemiology of America (SHEA) Public Policy and Government Affairs Committee, Diversity, Equity & Inclusion Committee, Community Based Healthcare Epidemiologist Task Force; and a volunteer member of the Infectious Diseases Society of America (IDSA) Leadership Development Committee and Coding and Payment Subcommittee. The other authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. – Task analysis feedback survey

The Task Analysis was useful to learn of the individual steps for this patient activity.

- ○ Not at all useful
- ○ Slightly useful
- ○ Moderately useful
- ○ Very useful
- ○ Extremely useful

The Task Analysis was useful to learn the possible challenges for the completion of this patient care activity.

- ○ Not at all useful
- ○ Slightly useful
- ○ Moderately useful
- ○ Very useful
- ○ Extremely useful

The Task Analysis helped me understand the potential solutions to challenges for completing this patient care activity.

- ○ Strongly disagree
- ○ Somewhat disagree
- ○ Neither agree nor disagree
- ○ Somewhat agree
- ○ Strongly agree

The Task Analysis was easy to use.

- ○ Strongly disagree
- ○ Somewhat disagree
- ○ Neither agree nor disagree
- ○ Somewhat agree
- ○ Strongly agree

The Task Analysis needs to be used for training all HCP in the patient care activity.

- ○ Strongly disagree
- ○ Somewhat disagree
- ○ Neither agree nor disagree
- ○ Somewhat agree
- ○ Strongly agree

I need more Task Analyses for completing patient care activities safely.

- ○ Strongly disagree
- ○ Somewhat disagree
- ○ Neither agree nor disagree
- ○ Somewhat agree
- ○ Strongly agree

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