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# THE ROLE OF HEALTHCARE STAFF IN HEALTH INSTITUTIONS IN THE KINGDOM OF SAUDI ARABIA IN ENHANCING INFECTION CONTROL

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**Abstract**

Healthcare-associated infections (HAIs) pose a significant threat to patient safety and healthcare quality worldwide. In the Kingdom of Saudi Arabia, healthcare workers play a crucial role in implementing and improving infection control practices. This paper explores the application of Human Factors Engineering (HFE) principles to enhance healthcare staff's capacity to reduce HAIs in Saudi Arabian healthcare institutions. The discussion focuses on three critical areas: hand hygiene adherence, personal protective equipment (PPE) use, and central line maintenance. Evidence from the literature demonstrates that infection control challenges in these domains are multifactorial, spanning cognitive, behavioral, environmental, organizational, and technological aspects. HFE offers a systems-oriented approach to address these challenges by aligning infection control initiatives with ergonomic design, clear protocols, effective training, and organizational support. In the context of Saudi Arabia's diverse

healthcare landscape and ongoing transformation under Vision 2030, integrating HFE principles into national policies, institutional protocols, and frontline practices is essential for empowering healthcare workers and advancing the Kingdom's commitment to world-class healthcare delivery. The success of infection control efforts in Saudi Arabian healthcare facilities depends on the collaboration between clinical expertise and systems thinking rooted in HFE. Future initiatives should build upon this synergy to ensure that infection control practices are resilient, sustainable, and tailored to the unique needs of the Saudi healthcare context.

Keywords: healthcare staff, Saudi Arabia, infection control.

## Introduction

Healthcare functions as a highly complex sociotechnical system, consisting of numerous interacting components that operate together to deliver patient care. These components include individual factors such as healthcare workers, the nature of clinical tasks, the technologies and tools utilized, the organizational infrastructure, and the physical and cultural environment in which care is provided. Each of these elements contributes to the overall performance and safety of healthcare systems. Additionally, a range of external influences, such as insurance reimbursement models, legal regulations, and national healthcare policies, further shape how care is delivered across different settings. Given this complexity, the application of human factors engineering (HFE) provides a valuable, systems-oriented approach that can be used to enhance safety, efficiency, and quality of care across healthcare environments.

Human factors engineering, which focuses on optimizing the interactions between people and the systems in which they work, has been used to address various safety and operational challenges in healthcare delivery. However, there are areas within the healthcare system that remain underexplored from an HFE perspective. One of the most pressing areas in need of further attention is infection prevention and control. Infection prevention and control is defined by the World Health Organization (WHO) as “a practical, evidence-based approach which prevents patients and health workers from being harmed by avoidable infections” (World Health Organization [WHO]). The emergence of dangerous, life-threatening infections, such as severe acute respiratory syndrome (SARS), Ebola, and others, has drawn international attention to the importance of robust and consistently applied infection control measures. These public health threats underscore the necessity for vigilant, evidence-driven infection prevention practices in all healthcare environments.

In the context of modern healthcare systems, preventing the transmission of infectious agents is not merely a clinical obligation but also a policy priority. The U.S. Department of Health and Human Services emphasizes that healthcare facilities must take proactive steps to prevent the spread of infectious organisms, including highly contagious and drug-resistant strains such as SARS and multidrug-resistant bacteria. This strategic priority has become even more critical with the rise of healthcare-associated infections (HAIs), which often originate from colonization during hospital stays. Many patients develop symptomatic infections due to exposure to harmful organisms such as *Clostridium difficile* or methicillin-resistant *Staphylococcus aureus* (MRSA), posing serious risks to both individual patients and the broader healthcare system. The continuous emergence and spread of antibiotic-resistant organisms only heightens the urgency for more effective and integrated infection prevention strategies.

In this regard, the Kingdom of Saudi Arabia presents a particularly relevant context. Healthcare institutions in the Kingdom have experienced significant transformation over the past

decades, with substantial investments in infrastructure, technology, and workforce development. Despite these advances, infection prevention remains a critical challenge. Healthcare workers in Saudi Arabian institutions—whether in public hospitals, private clinics, or primary care centers—play a central role in ensuring that infection control practices are implemented, monitored, and refined over time. The effectiveness of these practices often depends on the capacity of healthcare staff to integrate protocols into their workflow, respond to emerging threats, and engage with patients and colleagues to maintain high standards of hygiene and safety.

Yet, despite the key role that healthcare personnel play in infection prevention, the application of HFE methods and tools in this field has been limited. Jacob, Herwaldt, and Durso have noted that human factors principles have not been widely leveraged in the design and implementation of infection control programs, even though such approaches can offer structured solutions to many longstanding challenges in this domain. (Jacob et al., 2018). These include problems related to adherence to hand hygiene, correct use of personal protective equipment (PPE), and the prevention of central line-associated bloodstream infections. Incorporating HFE into these processes enables healthcare institutions to identify system-level barriers, improve workflow integration, and reduce cognitive and physical burdens on staff.

This paper aims to explore and highlight how healthcare workers in the Kingdom of Saudi Arabia contribute to enhancing infection control, particularly through the lens of human factors engineering. By examining practical examples where HFE models, principles, and methodologies have been applied, the discussion will emphasize the ways in which such integration supports infection control outcomes. Particular attention will be given to hand hygiene practices, the appropriate use of PPE, and the execution of central line-associated activities—each of which represents a critical point of intervention for infection control. These examples serve not only to illustrate the potential of HFE in improving infection prevention but also to underscore the pivotal role of healthcare professionals in driving change and ensuring safe care delivery in Saudi healthcare institutions.

**Improving Hand Hygiene Adherence**

Healthcare-associated infections (HAIs) remain a major concern in healthcare systems worldwide, with significant implications for patient safety, healthcare costs, and staff workload. In the United States alone, it is estimated that approximately 1.7 million patients develop HAIs each year, leading to nearly 100,000 preventable deaths. A central and highly effective strategy for preventing the transmission of these infections is ensuring that healthcare personnel (HCPs) consistently and correctly perform hand hygiene. Despite the proven efficacy of proper hand hygiene in reducing infection rates, adherence among healthcare workers remains alarmingly low. According to the WHO, average hand hygiene compliance hovers around 40% in healthcare settings. Even modest improvements in compliance rates have been shown to yield significant reductions in infection incidence, underscoring the critical nature of this practice.

However, efforts to improve hand hygiene adherence have met with mixed results in terms of long-term effectiveness and consistency. Existing interventions—ranging from training and awareness campaigns to automated reminders—have demonstrated variable outcomes across different healthcare environments. One reason for this variability may lie in the inherently complex nature of hand hygiene itself, which operates at the intersection of individual behavior and environmental or technological systems, such as the location and accessibility of hand sanitizer dispensers. Human Factors Engineering (HFE) offers a rich conceptual and practical toolkit for addressing this complexity. By analyzing and redesigning the interactions between healthcare staff

and their working environments, HFE provides evidence-based strategies for optimizing compliance and promoting sustainable behavior change in infection control practices.

A notable example of the application of human factors principles in the realm of hand hygiene is presented in the work of Sax et al., who employed a design-oriented HFE framework to conceptualize hand hygiene behavior based on critical infection transmission points. This framework was further refined to identify the "Five Moments for Hand Hygiene," which delineate specific points during patient care when hand hygiene is essential to prevent transmission of pathogens: before patient contact; before conducting an aseptic task; after exposure to bodily fluids; after patient contact; and after touching objects or surfaces in the patient's surroundings. While this structured approach provides clarity on when hand hygiene should be performed, actual adherence remains suboptimal. A study by Scheithauer, Batzer, Dangel, Passweg, and Widmer revealed that compliance with hand hygiene following the five recommended moments averaged only 42%, indicating significant gaps between guidelines and real-world practice. (Scheithauer et al., 2017).

One common explanation for these gaps centers on the belief that they stem primarily from training deficiencies among healthcare staff. Indeed, a lack of adequate training can lead to uncertainty or neglect of proper hand hygiene protocols. However, attributing noncompliance solely to training oversimplifies the issue and may overlook more systemic and context-specific factors that influence behavior. A broader and more nuanced understanding can be achieved by applying a sociotechnical systems perspective, which considers the complex interplay between individuals, technologies, tasks, organizational culture, and environmental conditions. For instance, Sax and Clack propose that hand hygiene failures may result not just from knowledge deficits, but also from flawed or incomplete mental models—internal representations that guide staff decisions and actions regarding infection control. These mental models are shaped by both clinical experience and environmental cues and may diverge from formal training or policy guidelines (Sax & Clack, 2015).

From this perspective, HFE can play a vital role in bridging the gap between intention and action by aligning system design with the cognitive processes and workflows of healthcare personnel. One practical intervention informed by this approach involves enhancing the visibility and convenience of hand hygiene opportunities. For example, placing hand sanitizer dispensers in high-traffic, immediately accessible, and visually prominent locations can significantly increase their use, as these design choices elevate the salience of hand hygiene and reduce the effort required for compliance. In Saudi Arabian healthcare institutions, where diverse clinical settings, staff backgrounds, and cultural contexts intersect, such system-level modifications may be particularly impactful. Healthcare professionals in the Kingdom, from nurses to physicians and support staff, are integral in modeling, promoting, and sustaining adherence to infection control practices. Thus, embedding HFE principles into routine workflow design and staff education can empower them to more effectively fulfill this critical role in infection prevention.

Through these efforts, Saudi healthcare institutions have the potential not only to improve infection control outcomes but also to create safer, more efficient, and more supportive environments for staff and patients alike. Recognizing and addressing the full spectrum of factors that influence hand hygiene behavior is essential for developing targeted, context-sensitive interventions that lead to lasting improvements in healthcare quality and patient safety.

In exploring the factors influencing hand hygiene adherence, Cure and Van Enk conducted an important investigation into how the usability of hand sanitizer dispensers affects healthcare workers' compliance with hygiene protocols (Cure & Van Enk, 2015). The concept of usability in

their study included a range of ergonomic and design-related factors such as the visibility and proximity of dispensers to both the entrance of patient rooms and the point of care, the ease of access without obstruction, appropriate placement along the natural path of workflow, and suitable installation height to facilitate routine use. Additionally, the study assessed the impact of standardization—defined as consistent placement of dispensers across various units or departments—on adherence behaviors. Their findings indicated that dispenser visibility and proximity to room entry points significantly improved adherence to hand hygiene protocols. In contrast, merely standardizing dispenser locations across units did not yield a meaningful improvement in compliance. This suggests that functional design, rather than uniformity alone, is key to fostering behavioral change among healthcare staff.

Building on these findings, Patterson et al. highlighted specific infrastructural and procedural barriers that hinder healthcare personnel from maintaining appropriate hand hygiene. Among the challenges identified were inconsistencies in the placement of hand sanitizer dispensers, physical separation between glove storage and sanitizer stations, and the inappropriate use of sinks for storing materials, rendering them inaccessible for actual handwashing. These environmental shortcomings disrupt the workflow and impede adherence. Notably, nursing staff in the study underscored the need to make dispenser locations more prominent and intuitive within the care environment. Supporting this observation, previous studies have demonstrated that increasing the perceptual salience of dispensers, for example, by integrating blinking LED lights, can significantly enhance hand hygiene compliance among healthcare workers. Another example of a human-centered design intervention is the physical demarcation of the patient care zone, which can be implemented by placing visual markers or tape on the floor to signal the boundaries of patient interaction spaces. Such environmental cues serve to cognitively prime healthcare staff about the need to perform hand hygiene upon entering or exiting the marked zones.

Further evidence from infection prevention literature supports the superiority of multifaceted strategies over single-method interventions. A growing body of research underscores that multimodal interventions—those that simultaneously target multiple behavioral, environmental, and cognitive dimensions—are more effective in achieving sustained improvements in hand hygiene adherence. The WHO has formalized this approach in its guidelines for hand hygiene improvement, which advocates comprehensive intervention strategies focused on five core domains: systemic infrastructure, educational and training initiatives, continuous performance evaluation and feedback, presence of visual and cognitive reminders in the workplace, and fostering a robust institutional safety culture that prioritizes hygiene. These components interact synergistically to create an organizational environment conducive to behavior change and long-term adherence.

A systematic qualitative review conducted by Smiddy, O'Connell, and Creedon further emphasized the complex range of factors that affect compliance with hand hygiene protocols among healthcare providers (Smiddy et al., 2015). The review aligns closely with the sociotechnical systems model, which posits that hand hygiene behavior is shaped by a dynamic interplay between individual characteristics, task requirements, available technologies, and organizational structures. This model is particularly useful in healthcare systems such as those in the Kingdom of Saudi Arabia, where healthcare professionals operate in diverse environments and must navigate both local cultural norms and global infection control standards.

In conclusion, improving hand hygiene adherence in healthcare settings requires a multifactorial and system-based approach that accounts for both physical and cognitive aspects of

the care environment. Elements such as dispenser design, placement within workflow patterns, and visual cues can enhance compliance, while broader multimodal interventions address the psychological, institutional, and cultural factors that influence behavior. Moreover, a deeper understanding of healthcare professionals' mental models—how they perceive and internalize hygiene protocols—is crucial for refining intervention strategies. In the context of Saudi Arabian healthcare institutions, where staff from varied backgrounds collaborate in dynamic care settings, such human factors engineering (HFE)-driven approaches can be instrumental in elevating infection control standards. Future research and implementation efforts should therefore focus on integrating these insights to optimize hand hygiene practices and empower healthcare staff in their vital role as frontline defenders against healthcare-associated infections.

**Utilization of Personal Protective Equipment (PPE) by Healthcare Professionals**

Personal Protective Equipment (PPE) serves as a critical barrier protecting healthcare professionals (HCPs) from exposure to potentially infectious biological materials, including bodily fluids, as well as microorganisms transmitted through contact, droplets, or airborne pathways. The significance of proper PPE usage has been highlighted in global public health crises, such as the Ebola virus epidemic and the outbreak of the severe acute respiratory syndrome-associated coronavirus (SARS-CoV). The Ebola epidemic in West Africa, which spanned from 2014 to 2016, led to over 28,000 confirmed infections and claimed more than 11,000 lives. Similarly, the SARS-CoV outbreak in the early 2000s brought international attention to infection control practices. In both cases, a substantial number of infections among healthcare providers were traced back to improper PPE doffing techniques, underscoring the critical importance of correct usage protocols. These incidents stress that healthcare workers, particularly in regions such as the Kingdom of Saudi Arabia, where healthcare systems face both regional epidemics and global threats, must be adequately trained and equipped to handle PPE with precision to ensure their safety and that of their patients.

Effective PPE usage is not solely a matter of equipment availability but rather represents a complex intersection of human behavior, equipment design, and the broader environment, which includes physical infrastructure, social practices, and policy frameworks. The use of PPE involves three distinct stages where breaches can occur: donning (putting on), active patient care, and doffing (removing the equipment). Each of these phases presents specific contamination risks. During donning, improper storage of PPE, use of previously contaminated gear, or incorrect application techniques can compromise protection. During patient care, hazards may stem from physically compromising the integrity of PPE, encountering design limitations, or succumbing to distractions such as using mobile devices beneath protective clothing. In the doffing phase, risks are associated with flawed removal techniques, incorrect handling or disposal of PPE, and accidental damage to the gear. In the context of Saudi Arabia, where healthcare settings often serve diverse patient populations and employ multinational HCP teams, it is crucial that institutional policies and training protocols address these risks comprehensively. The following section presents empirical findings from research that examines PPE donning and doffing behaviors, as well as insights into PPE design improvements.

**PPE Donning and Doffing Practices**

Puro and Nicastri observed that many healthcare workers during the SARS outbreak demonstrated insufficient knowledge of appropriate PPE removal procedures. Moreover, their analysis revealed that existing guidelines and informational resources were often inadequately detailed or, worse, contradictory, leading to increased risk of self-contamination during removal. This ambiguity in protocol highlights the pressing need for clarity in infection prevention

materials, particularly in high-risk contexts where PPE misuse can have fatal consequences. In the Saudi healthcare system, where multilingual and multicultural teams operate in tandem, it is vital to ensure that PPE guidelines are linguistically accessible, contextually relevant, and clearly articulated to minimize misinterpretation.

A study conducted by Beam, Gibbs, Boulter, Beckerdite, and Smith evaluated healthcare providers' PPE usage under simulated conditions involving both airborne and contact precautions. Participants performed care-related tasks while contamination was tracked using a fluorescent marker. The findings indicated that every participant violated at least one aspect of PPE protocol across all three phases of use. During donning, common issues included skipping respirator seal checks, failing to secure gowns properly, and incorrect sequencing. In the doffing phase, participants frequently deviated from the prescribed order of removal and mishandled masks. Additionally, some brought potentially contaminated materials with them upon exiting patient rooms. During patient care, lapses included direct contact with unprotected areas of their own bodies using contaminated PPE. The researchers concluded that healthcare workers lacked adequate understanding of contamination pathways. They also suggested that simulated training environments could be instrumental in uncovering behavioral gaps and facilitating safer practices. Within Saudi healthcare institutions, where clinical simulation centers are increasingly common, such training could be adapted to reflect local challenges and procedural nuances.

Zellmer, Van Hoof, and Safdar conducted an observational study outside of simulation contexts and found similarly alarming patterns. Their research revealed that 57% of healthcare professionals removed PPE in an incorrect order, 53% exited patient rooms without properly removing contaminated gear, and 40% disposed of PPE incorrectly. (Zellmer et al., 2015). These findings point to frequent noncompliance with established infection control protocols. The issue was further corroborated by Mitchell et al., who employed a standardized observational method to track PPE usage. They found that 66% of healthcare staff failed to don the recommended PPE, and 56% removed it in an improper sequence. These deviations suggest a need for more robust education and monitoring systems. In the Kingdom of Saudi Arabia, where patient volumes and clinical complexity are on the rise, especially in tertiary hospitals, strengthening such training programs is essential for frontline staff safety.

Mumma et al. applied a human factors risk analysis approach to examine errors in PPE removal, specifically focusing on high-risk Ebola-level protective equipment. In a simulation involving eleven highly experienced HCPs, the researchers employed failure modes and effects analysis (FMEA) to identify actions most associated with self-contamination (Mumma et al., 2018). The study concluded that lapses in hand hygiene and improper removal of powered air-purifying respirators were major contributors to risk. The authors emphasized that while PPE is intended to provide protection, it may paradoxically expose healthcare workers to greater harm if not designed with human usability in mind. For healthcare systems in Saudi Arabia, especially during national outbreaks such as MERS-CoV, the integration of ergonomic principles in PPE design and training becomes even more critical.

Using an HFE framework, Krein et al. observed PPE use in 325 hospital rooms across multiple units, aiming to classify and understand self-contamination failures. Their field notes revealed 283 failure events, of which 102 were violations (e.g., entering rooms without PPE), 144 were process or procedural mistakes (e.g., incorrect doffing sequences), and 37 were slips (e.g., wiping the face with contaminated forearms). This classification sheds light on the diverse origins of human error. The researchers concluded that because of the wide variety of causes for PPE

misuse, no single intervention strategy could comprehensively eliminate transmission risks. Rather, a multilayered, systems-oriented approach is needed (Krein et al., 2018). In Saudi Arabia, where healthcare facilities are rapidly advancing in terms of infrastructure and digital health adoption, the opportunity exists to embed HFE-informed strategies into policy and practice, thereby reinforcing infection control across all clinical touchpoints.

Evidence from earlier studies underscores that even with preparatory efforts such as reviewing PPE removal protocols immediately prior to doffing and providing step-by-step guidance during the procedure, a considerable number of healthcare personnel continue to make critical errors. For instance, Casanova, Alfano-Sobsey, Rutala, Weber, and Sobsey found that such preemptive instruction, although beneficial, was insufficient in eliminating mistakes during PPE doffing. These findings highlight the inherent complexity of the doffing process and the challenges in translating theoretical guidelines into precise, error-free practice. The implications are especially relevant in healthcare environments within the Kingdom of Saudi Arabia, where high patient turnover and multilingual healthcare teams may exacerbate the likelihood of procedural missteps despite access to protocol training.

In a similar vein, Kang et al. conducted a simulation study comparing two categories of PPE: basic/simple sets and full-body protective suits. Using fluorescent powder to track contamination, they observed that 92% of participants experienced contamination when using simple PPE and 66% were contaminated when using full-body PPE. Alarmingly, after undergoing training interventions, contamination rates during doffing remained high—91% of healthcare workers still exhibited some form of contamination in subsequent simulation sessions. The authors concluded rather pessimistically that these failures might stem from "natural flaws" in human behavior. (Kang et al., 2017). However, such an interpretation arguably underplays the significance of ergonomic PPE design improvements that could help mitigate these risks. Within Saudi healthcare settings, there is potential to reduce these contamination rates through investment in user-centered PPE designs that accommodate the behavioral tendencies and operational realities of frontline HCPs.

Taking a more constructive outlook, Casalino et al. examined the effectiveness of two distinct training approaches—standardized and reinforced—on the proper use of both standard and advanced PPE (Casalino et al., 2015). Each training modality included theoretical instruction, followed by hands-on practice sessions during which instructors provided verbal cues and reinforcements regarding correct donning and doffing techniques. The study found that over three successive training sessions, there was a noticeable decrease in contamination rates with both training types. However, reinforced training consistently resulted in greater adherence to proper protocols across PPE types. Nonetheless, optimal performance remained elusive, as noncompliance with best practices persisted even after all sessions. This finding is particularly significant for healthcare systems in Saudi Arabia, which often conduct periodic infection control workshops and may benefit from evaluating the efficacy and sustainability of training programs over time.

Training in PPE utilization continues to present multiple challenges across various healthcare contexts. Existing guidelines are frequently characterized by vagueness or a lack of detailed instruction, and inconsistencies in donning and doffing procedures are common due to variation in PPE product types (e.g., gowns with ties versus those that slip over the head). Additionally, the most effective instructional strategies, whether those involving real-time feedback, simulation-based learning, or skills proficiency testing, have yet to be firmly established in the literature. Implementing such resource-intensive educational methods also presents

logistical and financial challenges, including the need for tracking staff participation and assessing individual competency. As Bagian, King, Mills, and McKnight have argued, training, while necessary, is often considered a relatively "weaker" form of intervention when compared with systems-based or engineering solutions. This notion is especially pertinent in the Kingdom of Saudi Arabia, where the scale and complexity of healthcare infrastructure demand more integrated and sustainable approaches to infection control.

The significance of structured, high-quality training programs is further underscored by the findings of John et al., who surveyed healthcare workers regarding their experiences with PPE instruction. (John et al., 2016). Their study revealed considerable variability in training exposure among professionals. Notably, 15% of physicians reported receiving no PPE training at all, compared to only 1.4% of nurses. Furthermore, just 12% of physicians reported participating in annual PPE training sessions, while 47% of nurses reported the same. The most frequently cited training method was on-the-job learning (47.3%), followed by a mandatory annual computerized infection prevention module. However, only 43% of healthcare workers surveyed recalled completing the online training, pointing to its limited effectiveness and lack of engagement. In Saudi Arabian healthcare institutions, particularly those managing large workforces across different regions and levels of care, there exists a need to not only improve access to training but also to evaluate and enhance its impact on actual clinical behavior.

One potentially effective strategy for improving PPE proficiency involves incorporating immediate feedback into training sessions. Tomas et al. explored this approach using a simulation in which gown and glove removal were evaluated under fluorescent light (Tomas et al., 2015). The study showed that contamination occurred in 46% of the cases, with higher contamination rates noted during glove removal. The study identified a direct correlation between improper technique and increased risk of self-contamination. When immediate feedback was introduced during training, highlighting real-time errors, there was a notable reduction in both skin and clothing contamination during follow-up sessions. Importantly, this improvement was sustained during assessments conducted at one and three months post-training. For infection prevention efforts within Saudi hospitals, incorporating similar feedback mechanisms into mandatory training curricula could significantly enhance procedural compliance and long-term skill retention.

In the wake of the Ebola outbreak, a major initiative supported by the Centers for Disease Control and Prevention (CDC) aimed to supplement traditional PPE training with an innovative web-based educational platform. Developed by Gurses, Rosen, and Pronovost, the program utilized Human Factors and Ergonomics (HFE) principles to convert complex PPE usage protocols into simplified, task-based instructions. (Gurses et al., 2018). These redesigned materials aimed to eliminate ambiguities, enhance workflow design, and foster improved teamwork among HCPs managing patients with highly infectious diseases. Although promising in design, the program’s effectiveness remains to be validated through rigorous empirical testing. However, its development exemplifies how HFE-driven solutions can be strategically deployed in health systems such as those in Saudi Arabia, where scalable, technology-assisted training models are increasingly feasible given the country's investments in digital transformation and health informatics.

Efforts aimed at the redesign of personal protective equipment (PPE) to enhance usability and compliance among healthcare professionals (HCPs) have, to date, been relatively limited. Notably, Singleton and Johnson applied human factors and ergonomics (HFE) principles to develop an improved PPE storage cart intended to facilitate more consistent and correct PPE use. (Singleton & Johnson, 2018). The redesigned cart incorporated key usability features such as

standardized layout, visual aids in the form of picture labels, and clear step-by-step instructions on PPE application. In a before-and-after evaluation, PPE compliance was observed to be only 47% at baseline. However, following the introduction of the new cart system, compliance rose substantially to 81%, suggesting that even modest redesigns grounded in HFE methodologies can significantly enhance adherence to infection control procedures. For healthcare institutions within the Kingdom of Saudi Arabia, particularly those experiencing high patient volumes and staff turnover, such ergonomic innovations can serve as practical tools to support frontline staff in their infection control responsibilities.

In a separate but complementary study, DuBose et al. examined how the physical healthcare environment impacts PPE use by observing 41 HCPs during donning and doffing exercises across four dedicated Ebola treatment centers and one high-fidelity simulation facility (DuBose et al., 2018). The evaluation was conducted with trained observers who provided real-time guidance and assessment. Several challenges were identified, including suboptimal communication between observers and HCPs, limited visibility of the healthcare workers by supervisors, and physical design flaws within the donning and doffing zones. Specific environmental issues, such as inadequate space, absence of visual demarcation lines to define contaminated versus clean areas, and poor layout of doffing zones, were found to create confusion and contribute to procedural nonadherence. These findings emphasize the need for healthcare facilities, including those in Saudi Arabia, to consider environmental and spatial factors when designing or renovating clinical spaces, particularly those dedicated to infection prevention and control.

Collectively, the literature illustrates that PPE-related challenges are multifaceted and deeply rooted in both the design of equipment and the contexts in which it is used. The technical complexity of PPE, coupled with the procedural intricacies of correct donning and doffing, creates numerous opportunities for error. Central among these issues are deficiencies in communication surrounding which types of PPE are appropriate for different scenarios and how they should be correctly used. While there is a clear demand for more robust and effective training programs, a deeper organizational challenge lies in the inconsistent requirement or lack thereof for PPE-specific training across healthcare settings. Within the Kingdom of Saudi Arabia, such inconsistencies may be exacerbated by regional disparities in healthcare facility resources, variable training protocols, and differences in staff educational backgrounds.

Given the persistently low rates of PPE adherence, the application of human factors engineering holds considerable promise in addressing this issue from multiple fronts. Enhancements in equipment design, more intuitive training interventions, and environment-based modifications all offer potential routes to improve adherence. Importantly, these strategies should not be approached in isolation. Rather, adopting a sociotechnical systems framework, one that holistically integrates individual, technological, organizational, and environmental dimensions, provides a cohesive and effective avenue for addressing PPE nonadherence. For Saudi Arabian healthcare institutions aiming to strengthen infection control infrastructure, this systems-oriented perspective can serve as a foundational model for coordinated, sustainable improvements in the safe and effective use of PPE.

**Reducing Central Line-Associated Bloodstream Infections**

Healthcare-associated infections (HAIs) continue to pose a major risk to patient safety, particularly in intensive care units (ICUs), where over 400,000 patients in the United States acquire such infections annually. Among these, central line-associated bloodstream infections (CLABSIs) represent a leading cause of mortality. Over the past ten years, substantial progress has been made

in reducing the incidence of CLABSIs in U.S. ICUs, with an estimated 80% decline reported (Pronovost et al., 2016). This remarkable reduction is credited in large part to large-scale, evidence-based initiatives that have combined technical interventions with behavioral and organizational change strategies. One such prominent initiative, the Michigan Keystone project, implemented across 103 ICUs, demonstrated that significant improvement in CLABSI outcomes could be achieved by addressing both human and system-level factors.

The Michigan Keystone initiative incorporated a dual-focused approach by simultaneously targeting organizational culture and frontline healthcare provider behaviors. A key component of the intervention involved the establishment of a Comprehensive Unit-Based Safety Program (CUSP), which sought to cultivate a robust culture of safety among healthcare teams. Through CUSP, unit leaders were tasked with training staff to enhance their awareness of clinical hazards, improve communication, foster teamwork, and recognize and address safety lapses. The CLABSI prevention strategy also included a structured bundle of evidence-based practices. This bundle encompassed educational sessions for clinical personnel, standardized central line carts stocked with all necessary supplies, use of a procedural checklist to ensure compliance with safe line insertion protocols, empowerment of staff to halt procedures in the event of non-adherence, and daily evaluation of the necessity for line continuation. Notably, an analogous implementation in Spain revealed that deploying only the checklist component failed to produce significant changes in CLABSI rates. It was only when the comprehensive intervention, including cultural and organizational changes, was fully adopted that CLABSI rates declined. This finding underscores the importance of adopting a sociotechnical systems approach, which is highly relevant for Saudi Arabian healthcare institutions striving to integrate infection prevention efforts into existing clinical and organizational frameworks.

In addition to line insertion protocols, the maintenance of central lines plays a critical role in preventing bloodstream infections. Within this domain, the concept of adherence engineering has emerged as a valuable framework for promoting consistent compliance with complex clinical protocols. The central premise of adherence engineering is that adherence behaviors are not solely determined by individual intent or skill but are significantly influenced by external contextual elements. As such, modifying these external factors can enhance compliance with infection control standards. This framework outlines seven principles designed to improve adherence: (1) intentionally creating object affordances features that naturally guide user behavior, (2) embedding guidance within the task itself, (3) employing nudges to steer choices toward optimal behaviors, (4) setting intelligent default options, (5) providing actionable feedback, (6) minimizing cognitive load, and (7) reducing physical exertion required to complete the task. Each of these principles offers a practical avenue to support healthcare staff in adhering to standardized procedures, which is crucial for healthcare environments such as those in Saudi Arabia, where the workforce is diverse and often under time pressure.

Building upon this adherence engineering framework, Drews, Bakdash, and Gleed designed a central line maintenance kit explicitly structured around human factors engineering (HFE) principles. (Drews et al., 2017). The kit was intended to make adherence to central line maintenance protocols more intuitive and less error-prone by incorporating specific design features aligned with the aforementioned principles. These included clearly labeled compartments, logical sequencing of tools, integrated checklists, and visual cues to guide proper usage. The efficacy of the kit was evaluated in a 29-month pre- and post-intervention clinical study, which demonstrated a marked improvement in protocol adherence among clinical staff. More importantly, the study

reported a statistically significant reduction in CLABSI incidence following the introduction of the kit. This outcome provides compelling evidence that thoughtful application of HFE principles to medical tool and system design can substantially enhance clinical outcomes by supporting healthcare workers in consistent, correct task execution.

For healthcare institutions within the Kingdom of Saudi Arabia, such findings highlight the potential impact of systemic and ergonomic interventions on infection control. Given the complexity of clinical environments and the variability in staff training and background, especially among expatriate healthcare workers, tools that are designed with human usability in mind are particularly valuable. Integrating adherence engineering into both policy and practice can help frontline staff overcome environmental and procedural barriers, thereby reinforcing safe behaviors and improving patient safety outcomes. Moreover, the Saudi healthcare system's ongoing transformation under Vision 2030 provides a timely opportunity to embed such evidence-based approaches into national infection control strategies.

**Conclusion**

Infection control remains one of the most vital pillars of patient safety and healthcare quality worldwide, and its importance is particularly pronounced within the dynamic and rapidly evolving healthcare system of the Kingdom of Saudi Arabia. The role of healthcare staff in this context is central, not only in the execution of established infection prevention protocols but also in the co-creation, adaptation, and continuous improvement of these systems in response to emerging threats and systemic challenges. As this paper has demonstrated, integrating Human Factors Engineering (HFE) principles into infection control efforts offers a powerful and evidence-based approach to enhancing healthcare workers' capacity to reduce healthcare-associated infections (HAIs).

The findings reviewed in this paper clearly illustrate that infection control challenges—ranging from suboptimal hand hygiene adherence and improper personal protective equipment (PPE) use to inconsistent central line maintenance—are multifactorial. These challenges span the cognitive, behavioral, environmental, organizational, and technological domains. Healthcare professionals must not only possess the requisite knowledge but also operate within systems that support optimal behavior through ergonomic design, clear protocols, effective training, and organizational support. Through the lens of HFE, interventions can be more precisely targeted to the specific barriers that healthcare staff encounter in their daily workflow, thereby reducing cognitive and physical burden while increasing safety and efficiency.

In Saudi Arabia’s healthcare institutions, where multilingual, multicultural teams serve diverse populations across urban and rural settings, the importance of system-based approaches is further amplified. The strategic alignment of infection control initiatives with HFE methods, such as the redesign of hand hygiene infrastructure, ergonomic improvements in PPE use and storage, or adherence-engineered kits for central line maintenance, demonstrates how health systems can empower staff to act effectively. Moreover, as the Kingdom moves forward with its Vision 2030 healthcare transformation agenda, the time is ripe for embedding these principles into national policy, institutional protocols, and frontline practices.

Ultimately, the success of infection control efforts in Saudi Arabian healthcare facilities depends on the extent to which healthcare workers are supported by thoughtfully designed systems. Empowering staff through education, human-centered tools, environmental cues, and robust institutional safety cultures is not just beneficial—it is essential. As this paper has emphasized, the collaboration between clinical expertise and systems thinking rooted in human factors engineering is not only capable of improving infection prevention outcomes but is also

critical to advancing the Kingdom's commitment to world-class healthcare delivery. Future initiatives should continue to build upon this synergy, ensuring that infection control practices are resilient, sustainable, and tailored to the unique needs of the Saudi healthcare context.

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