Commentary

Overcoming COVID-19: What can human factors and ergonomics offer?

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Abstract

A novel coronavirus disease, named coronavirus disease 2019 or COVID-19, which sparked an outbreak in Wuhan, China in December 2019, is now a pandemic. The rapid spread of this disease from one to more than 155 regions worldwide in 2.5 months highlights the need for better preparation to manage a pandemic. In this commentary, we describe how Human Factors and Ergonomics (HFE) can contribute to the COVID-19 pandemic response. Specifically, we provide an example of how HFE methodologies informed workflow redesigns implemented as part of COVID-19 pandemic preparations in an academic pediatric ambulatory clinic. We then identify key mechanisms and areas where HFE can contribute to and improve the effectiveness of a pandemic response: Just-in-time (JIT) training development, adapting workflows and processes, restructuring teams and tasks, developing effective mechanisms and tools for communication, engaging patient and families to follow the recommended practices (e.g., social distancing, revised hospital visitation policies), identifying and mitigating barriers to implementation of plans, and learning from failures and successes to improve both the current and future pandemic responses. We recommend integrating HFE approaches and tools across health care systems, state health organizations, and the Centers for Disease Control and Prevention (CDC) as they confront this pandemic.

Keywords

COVID-19, safety, pediatrics, ambulatory care, ergonomics, risk evaluation and mitigation, human factors

Introduction

A new coronavirus, SARS-CoV-2, that sparked a respiratory disease outbreak in Wuhan, China is now a pandemic. The coronavirus disease 2019 (COVID-19) outbreak was reported in December 2019, and the World Health Organization (WHO) declared it a pandemic on 11 March 2020. As of 16 March 2020, the virus infected over 180,000 people (confirmed cases) and killed more than 7000 people worldwide.[1] The rapid escalation of a localized outbreak to more than 155 regions worldwide within 2.5 months highlights the importance of being prepared to manage a pandemic. As of this writing, significant portions of the world have experienced travel, business, and healthcare disruptions due to the pandemic.

We believe that one significant challenge to addressing the COVID-19 pandemic is a health care system that is not adequately designed to support human performance for a large-scale health crisis. Efforts thus far have not systematically considered the complexities of human cognition and behavior in pandemic preparation and responses, even though individuals are working as part of teams in complex, sociotechnical work systems, such as staff working in emergency

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departments or ambulatory care clinics. This is surprising given the magnitude of evidence and knowledge from human factors and ergonomics (HFE) describing how to design, adapt, and reconfigure health care work systems (e.g. primary care clinics) to support individual and team performance under high-risk, high-stakes situations.[2,3] Our goal in this commentary is to offer concrete directions and examples for how HFE can help overcome the current pandemic and future similar large-scale public health threats. Our examples will use HFE principles and methods that informed the preparation of an academic hospital-affiliated pediatric ambulatory care clinic in anticipation of the COVID-19 pandemic.

Why can HFE help?

HFE is a discipline that examines the design of individual work system components and the interactions with each other, taking into account human capabilities and characteristics, with the goals of achieving optimum human safety and performance.[4] HFE experts are formally trained to design and adapt/reconfigure work systems to maximize individual and team performance under high-risk, high-stakes environments, while minimizing the introduction of new significant safety risks or unintended consequences into the work system.[5] Specialists use various conceptual approaches and methods to identify barriers and enablers to consistent compliance with any guidelines and protocols. For a patient under investigation (PUI) for COVID-19 in a pediatric ambulatory care clinic, initial steps include screening, registration, and isolation protocols. Based on the in-depth, multimethod investigations conducted in collaboration with other key stakeholders, HFE specialists can inform the development of appropriate solutions to support individual and team performance in epidemic and pandemic situations. Some solutions can be highly practical and developed quickly with minimal resources, such as within hours or days (e.g. developing usable signage and checklists to support distributed or team cognitive work) with input from one or two HFE specialists. Other solutions may take longer and require a larger group of experts. For example, the HFE-informed web-based training development for donning/doffing personal protective equipment (PPE) during the Ebola epidemic took 10 days and required an interdisciplinary team of 40 experts.[3]

How HFE contributed to previous epidemic response efforts: The case of Ebola

When the Ebola outbreak hit in 2014, the Centers for Disease Control and Prevention (CDC) developed guidelines for proper donning and doffing of PPE to prevent transmission of Ebola from infected patients to health care workers (HCWs). These guidelines were rapidly assembled under extreme time pressure and high stakes. However, proper PPE donning and doffing is critical and complex, requiring unwavering attention under trying conditions and guidelines. Any slip or lapse can lead to contamination and infection with this deadly virus. In order to disseminate robust guidance to thousands of HCWs responding to the Ebola epidemic, we convened 40 individuals with expertise in infection prevention, medicine, nursing, instructional design, videography, and HFE to develop a web-based training program for how to safely don and doff PPE (http://www.cdc.gov/vhf/ebola/hcp/ppe-training/index.html?s_cid = cs_021). We conducted an HFE-based proactive risk assessment to identify how each step of the PPE donning and doffing process may fail, and used this analysis to create the online training. For example, we aimed to reduce ambiguity in the Ebola PPE donning/doffing guidelines by providing detailed and clear instructions showing how to put on boots. The training module also clarified the team composition and roles during donning/doffing. Our HFE-based analysis revealed that three HCWs, rather than the recommended two, were needed for safe donning/doffing of Ebola PPE. The training videos were viewed >320,000 times within a month of release on the CDC website.[3]

How HFE has informed the COVID-19 pandemic preparations: A pediatric ambulatory clinic example

In late February 2020, pediatric ambulatory care team leaders began COVID-19 outbreak preparations, and in early March they developed a detailed workflow which included three sub-processes to keep patients/families and HCWs safe. These processes were to: (1) screen patients at the time of arrival to the clinic; (2) register patients at the clinic; and (3) isolate any patient who may potentially have the new coronavirus. Team members contacted an HFE specialist (APG) for expertise in designing/adapting complex work systems and processes subject to high safety risks. An interdisciplinary team including five physicians, five nurses, one clinic administrator, and one HFE convened to develop detailed workflows informed by the HFE-based proactive risk assessment methodology.

Methodology overview

Given the urgency, we adapted and used a simplified version of a health care failure modes and effects analysis (HFMEA),[6] combined with in-situ simulations and

debriefings,[7] to identify potential failure modes and associated safety hazards, which, in turn, informed an iterative redesign of the three sub-processes and associated workflows to mitigate safety risks. An HFMEA or any proactive risk assessment methodology asks at each step in the process, "*How could the system fail?*", and uses input from multiple stakeholders and risk identification methods (e.g. in-situ simulation, expert panel) to identify how to adapt/reconfigure work system elements to reduce the likelihood of failure. Additionally, HFE-informed debriefings after caring for patients who presented to the clinic with concerns for COVID-19 exposure also informed the iterative redesign of workflows.

Conceptual approaches guiding the proactive risk assessment

Our proactive risk assessment was informed by two complementary HFE-based conceptual approaches: the Systems Engineering Initiative for Patient Safety (SEIPS),[2] and the systems ambiguity framework.[8] According to the SEIPS model,[2] how well a care work system is designed (*structure*) affects the safety of care processes (*process*), which in turn affects patient/family and HCW safety (*outcomes*). In the SEIPS model, a "work system" has five elements: individuals (e.g. HCWs with varying levels of non-technical skills), tools and technologies (e.g. PPE, checklists), tasks (e.g. putting on a mask), physical environment (e.g. ambulatory clinic waiting room area), and team/organization (e.g. team composition and roles, culture, leadership support). Thus, SEIPS accounts for the complexities and interactions between components of the work system. First, our interdisciplinary team used the SEIPS model and identified the following potential failure modes and associated hazards in the pediatric ambulatory clinic work system:

- How can we standardize screening and communication with the patient/family during registration (e.g. scripts, cognitive tools)? (*tools*/*technologies*)
- If several patients arrive within minutes of each other, how can we register and isolate each patient safely and efficiently while not risking other patients' and HCWs' safety? (*task*/*workload management* and *team*/*organization*)
- How to minimize the risk of patients/families putting the mask on incorrectly or not keeping it on? (*task*, *tools*/*technologies*)
- How to minimize time to get in and out of the isolation room? (*tools*/*technologies* and *team*/*organization*)
- Because the clinic does not have anterooms (*physical environment*), how will we operationalize safe PPE donning/doffing to minimize risk of contamination (*task*)?

Second, the interdisciplinary team used the systems ambiguity framework to identify any ambiguities with the guidelines, protocols, and procedures. Ambiguity in work systems is a well-known reason for noncompliance with guidelines and protocols and process failures.[8] The following potential failure modes and hazards were identified:

- If a patient screens positive, who is responsible for escorting the patient to the isolation room? Who is responsible for making sure the isolation room is cleaned and restocked? (*responsibility ambiguity*)
- How will we clean and reuse PPE more than once? (*method ambiguity*)
- How will we communicate with patient/family member once they are in the isolation room? (*method ambiguity*)
- What information should be told to other family members who would like to see the patient? (*task ambiguity*)

Procedural details

We developed three scenarios (with variations in travel history, symptoms, number of family members) and conducted a total of five in-situ simulations. Each simulation was followed by a 1 to 1.5 h in-depth debriefing session. Additionally, the interdisciplinary team had two 1.5 h meetings, in preparation for the simulations and other tasks related to the workflow design/adaptation. Each team member was instructed to take detailed notes regarding potential failure modes and risks during simulations. During each debriefing session, our interdisciplinary team reviewed each workflow/process in detail and shared any observations made and insights gained from the in-situ simulations. We took detailed notes both during the in-situ simulations and the debriefing sessions and used these notes to iteratively revise the protocols for the three sub-processes before the next in-situ simulation session, and distributed these updated workflow documents to those observing the in-situ simulation to take detailed notes. After five in-situ simulations and debriefing sessions, workflows were shared with and reviewed by a larger group of ambulatory clinic professionals; additional adjustments were made based on feedback.

Table 1 summarizes concrete, practical examples for how the HFE-based proactive risk assessment process informed the design and adaptation of workflows. It is important to note two key points about this analysis: (1) Table 1 does not present complete results, rather provides some examples to show how HFE-based proactive risk assessment can support workflow design and adaptation; (2) Given the highly fluid and rapidly changing nature of the COVID-19 response, this workflow was subject to modifications at any time (e.g. changes to infection

Table 1. Examples of workflow redesigns informed by HFE-based proactive risk analysis for COVID-19 pandemic preparations at an academic pediatric ambulatory clinic.

Steps in the process (incomplete)	Sample failure modes and associated hazards in the work system	Actions/revisions in the protocol and processes
Screening by security: Patient/family arrives to security desk		
Screen according to the latest recommendation from the HEIC	-Guidelines are changing very frequently -Security does not screen family (e.g. high volume patients, fatigue, unaware) -Patient bypasses security screen	-Hospital management implemented QR codes to inform frontline HCWs with updates on screening guidelines -Need for messaging to include all team members who have contact with patient to screen.
If patient answers yes to screening questions, provide mask to patient and family if not already wearing one.	-Patient/family member does not know how to put the mask on correctly -Patient (child) removes mask	-Develop visuals providing step-by-step guidance on how to put on and take off mask. -Reinforce messaging to patient/family.
Patient/family waits at security desk until PSC becomes available at the front desk.	-Patient may cough on the security desk before putting the mask on	-Add a step to the checklist instructing security to wipe down security desk and kiosk. -Use specific and unambiguous language (wear gloves and use purple top wipes; surface should remain wet for 3 min).
Registration (If screened positive)		
PSC starts screening process	-Siblings accompanying the PUI may be running around the waiting room area -Language barrier to understanding verbal screening	-Ask family members *explicitly* to keep children together (not running around in waiting area) for the safety of others in addition to providing written instructions -Visual checklist with screening questions available for patients in different languages
PSC needs to get name and cell phone number of patient/family member to allow communication if needed	-PSC may forget to get contact information	-Include this question as part of the checklist that will be used by the PSC
PSC calls nursing station and continues the registration process until a nurse or a certified medical assistant arrives to escort the patient to the isolation room	-The phone number for nursing station may not be accurate -No one is available in the nursing station to respond	-Test and make sure all contact information is up-to-date. -Ask another team member to notify the nurse or the certified medical assistant
Isolation		
Prepare the isolation room	*Isolation room may not be ready due to variety of factors such as*: -Role ambiguity: Which team member is responsible for preparing the room? And for escorting the patient from the waiting room area to the isolation room? -Method ambiguity: How to prepare the isolation room? What supplies/equipment do I need? Where to find the necessary supplies? Where should I move patients who are already in the isolation room?	-Clarify the isolation protocol. Two team members are needed. One is responsible for preparing the isolation room, while the other is responsible for escorting the patient to the isolation room. -Develop and pilot test an isolation room preparation checklist. Provide step-by-step guidance on how to prepare the room, including specific and accurate information on where to find the necessary supplies (e.g. isolation cart, hepafilter, beside commode, red trash bag, etc.) Store all necessary supplies together to the extent possible to reduce walking time and improve efficiency.
Escort patient/family to isolation room	-International patient/family may ask for the translator to come to the isolation room	-Clarify in the nurse/medical assistant checklist that translators are not allowed to go inside the isolation room. -Request translator's cell phone and ask him/her to wait outside

HEIC: hospital epidemiology and infection control; HCWs: health care workers; PUI: patient under investigation; PSC: patient service coordinator.

Table 2. Sample HFE contributions and relevant methodologies for outbreak management.

HFE-informed approaches and strategies	Sample methods and intervention examples
Preparation for an outbreak	
Develop/adapt user-friendly cognitive tools, checklists to operationalize the process	Design visuals, scripts, checklists to support cognitive work based on usability and other HFE-based design principles
Improve usability of any guidance documents and guidelines	Conduct practical and formative usability evaluations (e.g. heuristic analysis conducted by an HFE expert within 15 min or so)
Design/adapt care processes (such as the patient registration and isolation processes in a clinic)	HFE-based proactive risk assessment
Develop training (e.g. on PPE donning/doffing, on resuscitation team work while wearing PPE)	Just-in-time training (e.g. for PPE donning/doffing) Team training (training on non-technical skills) In-situ simulationsDevelopment of competency assessment systems
Identify strategies to mitigate physical and cognitive limitations as a result of wearing PPE	Adapt/reconfigure work system to support communication (e.g. whiteboards and mobile phones dedicated to each negative pressure room, closed-loop communication)
Identify information requirements to support front-line HCWs	Cognitive task analysis methods and techniques
Develop mechanisms to communicate efficiently across people, time, and locations	Use human-centered design approaches to iteratively develop and pilot usable communication tools and mechanisms, and effective messaging strategies
Identify the best approaches to communicate with and engage patient/families to increase compliance with the recommended protocols and behaviors such as social distancing and hospital visitation policies	Use human-centered design approaches to iteratively develop and pilot usable communication tools and mechanisms, and effective messaging strategies
During the outbreak: Implementation and adjustments as necessary	
Identify barriers to and strategies for successful implementation of plans, and iteratively improve the work systems. Reevaluate and adjust plans as needed based on the evolving nature of the outbreak.	Sample HFE methods include direct observations, contextual inquiry, debriefing sessions, pilot evaluations of redesign efforts. Inform day-to-day decisions based on principles from theories of resilience and adaptive capacity, and naturalistic decision making, etc.
After the outbreak: Learning from this outbreak to improve the next response	
Conduct a comprehensive analysis of the outbreak response, identify strengths and weakness in the planning, preparation, and execution stages, with the goal of learning from failures and successes to inform future outbreak preparations	Accident investigation and root cause analysis methods and approaches.Cognitive task analysis methods (e.g. critical decision method interviews, direct observations), and usability evaluation of cognitive tools/technologies used during outbreak (e.g. usability of the EHR-based screening tool).

HFE: human factors and ergonomics; EHR: electronic health record.

control guidelines, ongoing considerations for transitioning to telehealth). However, the HFE-based proactive risk assessment approach described in this paper can be applied to any workflow redesign and adaptation.

How else can HFE help with this pandemic and other similar threats to public health safety?

Table 2 summarizes other ways HFE can contribute to the effective management of the COVID-19 pandemic, and future similar threats. Below, we highlight two of these areas.

Usability evaluation of the 'guidelines' or 'guidance documents.': HFE can improve the usability of the guidelines and any guidance documents released to HCWs and the general public. For example, when the guidance documents were being prepared by CDC for Ebola preparation efforts, our interdisciplinary team of 40 experts conducted formative usability evaluations of the actual guideline and worked in close collaboration with CDC as they revised the guidelines simultaneously.

Outbreak investigation: HFE and safety science principles and methods have informed large scale accident investigations, such as Three-Mile Island and Chernobyl accidents.[9] Similar HFE-based approaches can be adapted and used to further improve and enrich current health care outbreak/epidemic/pandemic investigation methodologies and lead to more effective and sustainable interventions. Most traditional outbreak investigations focus on identifying active failures (e.g. factors at the "sharp-end," such as nurse noncompliance with the hand hygiene protocol), while latent factors (e.g. organizational culture, leadership practices, teamwork, design

of medical devices, physical layout) are typically not investigated in-depth. Moreover, any learnings from these investigations are not widely and systematically shared. Cognitive task analysis,[10] a set of HFE methods, can be particularly useful because the health care work is cognitively intense and the patient and HCW safety rely heavily on how well the distributed (team) cognition is supported across locations, people, and time. For example, are hospital epidemiology and infection control (HEIC) staff and front-line workers on the same page (shared mental model) with respect to COVID-19 response protocols and practices? Failure in team cognition (e.g. inadequate shared situational awareness, miscommunication or lack of communication) is a major contributor to almost all major accidents and inadequate emergency/disaster responses.[11–13] In the aftermath of this pandemic, it will be essential to use HFE approaches and methods to learn from both failures and successes and globally share these learnings to minimize the impact of such outbreaks. Otherwise, we will keep reinventing the wheel when the next large infectious disease epidemic hits.

Conclusions

Clear examples of how HFE can help with pandemic management exist. Warning HCWs to be diligent when following guidelines and sending long and confusing email messages encrypted with critical information, in the midst of a pandemic is ineffective and hazardous. Science-based approaches that consider human cognition and behavior while working in complex work systems, such as HFE, are needed to improve pandemic management. HFE can help prepare work systems to be robust and have adaptive capacity to withstand the uncertainty and fluidity during a pandemic, when national, state, and institutional policies can change daily or even hourly. In order to overcome the COVID-19 pandemic and future pandemics, we recommend involving HFE expertise at all levels of outbreak management, from preparation and planning to execution and investigation.

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