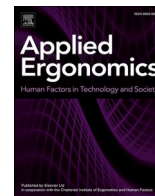




Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



Human Factors and Ergonomics (HFE) applications in responses to the COVID-19 pandemic: Lessons learned and considerations for methods

Abigail R. Wooldridge^{a,*}, Eva-Maria Carman^b, Anping Xie^c

^a University of Illinois at Urbana-Champaign, USA

^b Trent Simulation and Clinical Skills Centre, Nottingham University Hospitals NHS Trust, UK

^c Armstrong Institute for Patient Safety and Quality, Department Anesthesiology and Critical Care Medicine, Johns Hopkins University School of Medicine, USA

ARTICLE INFO

Keywords:

1. COVID-19
2. HFE in Public health crises
3. SEIPS

ABSTRACT

Human Factors and Ergonomics (HFE), with the goal to support humans through system design, can contribute to responses to emergencies and crises, like the COVID-19 pandemic. In this paper, we describe three cases presented at the 21st Triennial Congress of the International Ergonomics Association to demonstrate how HFE has been applied during the COVID-19 pandemic, namely to (1) develop a mobile diagnostic testing system, (2) understand the changes within physiotherapy services, and (3) guide the transition of a perioperative pain program to telemedicine. We reflect on methodological choices and lessons learned from each case and discuss opportunities to expand the impact of HFE in responses to future emergencies. The HFE discipline should develop faster, less resource intensive but still rigorous, methods, increase available HFE expertise by growing the field, and proactively enhance individual and public perception of the importance of HFE in crisis response.

1. Introduction

Human Factors and Ergonomics (HFE) studies, designs, and optimizes how humans engage in effortful activity to achieve goals (i.e., work) in complex sociotechnical systems (Carayon, 2006). It has been routinely and repeatedly argued that HFE is beneficial for the health and well-being of the humans in and for the efficiency and productivity of those systems – good ergonomics is good economics (Hendrick, 1996). In health care, much HFE work has focused on improving the outcomes of patients, health care professionals, and health care organizations. The value of HFE to health care quality and safety is increasingly recognized (Hignett et al., 2013). Given its rich approach to system design and its attention to safety, health, and well-being, it is no surprise that HFE can be applied to address the novel, uncertain and time-sensitive situations that have arisen as a result of the COVID-19 pandemic.

There have been efforts worldwide to apply HFE in response to the COVID-19 pandemic. In the United Kingdom (UK), the Chartered Institute of Ergonomics and Human Factors (CIEHF) rapidly produced documents with advisory HFE guidance for a variety of topics during the pandemic, including the physical, mental and social health of children studying and learning from home, the safe and effective rollout of time-critical vaccination programs, sustainable organizational changes of

health care systems, and the design and use of ventilators (CIEHF, n.d.). The method for this rapid document creation process has been described by Hignett et al. (2021). The 2021 IEA Triennial Congress included nine sessions with more than 50 presentations focusing on HFE contributions to the pandemic response, including but not limited to clinical settings, working at home, education, communication, coordination and humanitarian response (Adam and Bengler, 2021; Brusaca et al., 2021; Godoy et al., 2021; González et al., 2021; Griebel and Smith, 2021; Heiden et al., 2021; Keller et al., 2021; Voronina et al., 2021; Zenderski and Miranda de Oliveira, 2021).

As of January 3, 2022, of the 43 articles published in the journals of *Ergonomics* and *Applied Ergonomics* that feature the word “COVID” in the text, only 12 articles explored HFE topics in relation to the COVID-19 pandemic specifically. These include the use of face masks, gloves, and other personal protective equipment (PPE) (Janson et al., 2022; Mumma et al., 2022; Preece et al., 2021), psychological distress in airline pilots as a result of the pandemic (Alaminos-Torres et al., 2021), temperature screening at work (Goggins et al., 2022), physical activities of home-based office workers (Dillon et al., 2021), face-touching behavior during driving (Ralph et al., 2021), effect on travel (Beh et al., 2021), the relevance of distributed situation awareness in light of the pandemic (Salmon and Plant, 2022), access to prehospital

* Corresponding author.

E-mail address: arwool@illinois.edu (A.R. Wooldridge).

emergency health care systems (Arcuri et al., 2022), the necessity of HFE for enhancing work (de Winter and Hancock, 2021) and the impact of HFE on considerations for the field “future of work” (Bentley et al., 2020). In addition, the journal of *Human Factors and Ergonomics in Manufacturing and Service Industries* published a special issue with seven research articles and two review articles focusing on the HFE response to COVID-19, including the safety and accessibility of public spaces during the pandemic (Stevens et al., 2021), decision-making regarding the reopening of places of worship (Rothrock et al., 2021), the validation of cognitive models in the pandemic context (Stone et al., 2021), anthropometric, environmental, and psychosocial factors affecting distance learning during the pandemic (Ayyildiz and Taskin Gumus, 2021), the optimization of the return from lockdown (Salmon et al., 2021), safety in construction (Stiles et al., 2021) and rail operations (Naweed et al., 2021) during the pandemic, and the impacts of the pandemic on work (Sigahi et al., 2021) and work-life balance (Gulotta et al., 2021).

As highlighted by the previously mentioned publications and presentations, there has been extensive documentation of the contribution HFE can make in different industries regarding changes in work due to the pandemic. However, there has been relatively little published on the reflection on how our own ways of working have changed as a result of the pandemic. Although it has been highlighted that there is a need to reflect how work changes as a result of macro global factors, and the implications for HFE practice and the profession are starting to emerge (Bentley et al., 2020), little is available documenting the effect of the pandemic on the application of HFE and the way we as HFE specialists work. In this paper, we fill this gap, building on reflective discussion from the COVID-19 session 4 at the 2021 IEA Triennial Congress and demonstrate how the pandemic has affected the application of HFE within health care. We present three cases applying HFE to (1) develop a mobile diagnostic laboratory system (Wooldridge, 2021), (2) understand the changes, challenges and aspects that work well during the initial response to the pandemic within the physiotherapy service of one large hospital trust (Carman et al., 2021), and (3) guide the transition of a perioperative pain program from in-person to telemedicine care (Xie et al., 2021). After summarizing each case, we reflect on methodological choices and lessons learned from each case. We then discuss opportunities to expand the impact of HFE in responses to future pandemics and other public health emergencies.

2. Case 1: Macroergonomics of laboratory design

2.1. Background

Laboratory testing is one key to contain outbreaks of infectious diseases (Kelly-Cirino et al., 2019). Frequent testing supports early detection of infection, leading to faster quarantine of persons with the disease to slow disease spread, and guides decision making for community leaders (e.g., restrictions on travel, requirements for masks). In the beginning of the COVID-19 pandemic, few tests were available due to supply chain issues (e.g., scarcity of materials, disrupted transportation networks). A real-time reverse transcription polymerase chain reaction (rRT-PCR) test, covidSHIELD, was developed and deployed at the University of Illinois at Urbana-Champaign beginning in June 2020 to avoid supply chain challenges and provide quick and accurate results at low cost (Ranoa et al., 2020). However, covidSHIELD was initially designed and implemented in permanent, pre-existing laboratory space. One important consideration related to the laboratory space is the biosafety level (BSL) of the laboratory – the Centers for Disease Control (CDC) specified that such laboratories should be BSL-2 with unidirectional airflow and BSL-3 (a higher level of safety) precautions, such as areas for donning and doffing and respiratory protection (National Center for Immunization and Respiratory Diseases (U.S.). Division of Viral Diseases., 2020). These laboratory spaces, while relatively common on university campuses and in some health care systems, were not equitably accessible and available across the country, exacerbating the

disparities in health outcomes observed in the United States (Lieberman-Cribbin et al., 2020). A mobile laboratory able to perform the covidSHIELD test, to be deployed to areas with unmet testing needs, could enhance the national public health response to COVID-19, improve equitable access to testing services and support public health responses. Drawing on principles of systems ergonomics (Wooldridge, 2021), the design of a mobile laboratory should be part of a larger testing system that considers humans (e.g., patients, technicians) in a holistic testing system to ensure the success of the mobile laboratory, including from collection of the sample from patients to delivery of the test results. Thus, the objective of this project was to design the mobile testing system (see for additional details <https://grainger.illinois.edu/news/features/illinois-mobile-shield>).

2.2. Methods

Following a charge from administration at the University of Illinois, a multidisciplinary team was assembled to design the mobile testing system (Hale-Lopez et al., 2021). The team followed a human-centered design process (ISO, 2019) guided by systems ergonomics principles (Dul et al., 2012; Edwards and Jensen, 2014; Wilson, 2014; Zink, 2014) while adopting HFE methods for process analysis (Wooldridge, 2021). This project began in July 2020, so the team conducted in-person time and motion analysis through observations of the work at specimen collection sites and a functional, permanent laboratory (see <https://hfss.illinois.edu/files/2021/12/Observations-Sheet.pdf> for observation data collection tools). The team also reviewed protocols, procedures and information about laboratory certifications from quality assurance and research safety during meetings held in-person and by video conference. Based on the observations and historical document review, the team developed an initial process diagram using the Systems Engineering Initiative for Patient Safety (SEIPS) process modeling method (Wooldridge et al., 2017, 2022). The team developed multiple representations of the process, including a view focused on information flow that informed the design of the laboratory information management system (LIMS). Simultaneously, the team iteratively refined a floorplan, first with a computer-aided design (CAD) model, which was then printed at full scale, refined at an in-person collaborative design session that included simulation of the process at increasing levels of fidelity (i.e., the team simulating the process on the floor plan, then adding three-dimensional mockups of equipment). The team refined the floorplan, collection site and laboratory processes in sessions in-person and over video conferencing following the collaborative design session, involving staff from the office of research safety and the on-campus laboratory as subject-matter experts. In parallel, the team refined the design of the LIMS during sessions conducted in-person and over video conferencing. The team also designed a new specimen collection device to fit with a variety of test tubes, ensuring flexibility at the specimen collection site.

When the design of the specimen collection site and laboratory layouts and processes were nearly complete, including the assembly of a functioning laboratory prototype with all required equipment and materials, the team conducted two failure mode and effects analyses (FMEAs) – one for the collection site and one for the laboratory – to inform the final design of the testing system by proactively identifying potential breakdowns in the process that could lead to inaccurate or invalid test results as well as worker harm. The FMEA of work at the collection site was conducted over Zoom, facilitated by two human factors researchers. Four participants in the collection site FMEA included three workers from the campus specimen collection sites and one software developer. The FMEA of work at the laboratory was conducted in-person at the prototype laboratory and was facilitated by two human factors researchers. Seven participants in the laboratory FMEA included the quality assurance coordinator, the faculty principal investigator and a laboratory technician in the on-campus COVID-19 laboratory, two software developers and the operations executive officer and

laboratory director from the organization licensed by the university to translate the design of the laboratory system. Based on the results of the FMEA, small changes were made to the floorplans and process designs. Finally, a series of paired sample validation studies were conducted to validate the specimen collection device and the mobile laboratory process.

2.3. Outcomes

The HFE work in the project (i.e., observations, historical document review, FMEA) were incorporated in a set of SEIPS-based process maps (Wooldridge et al., 2017) that represent the sociotechnical system involved in the testing system. This includes identifying the work system elements (Carayon et al., 2020), examples of which follow:

- Team, e.g., the patients providing the saliva specimen, the collection site workers, the laboratory technicians.
- Tasks, e.g., registering the patient, providing the sample, heating the samples in a hot water bath, placing the samples on racks, preparing reagents.
- Tools and technologies, e.g., computer workstations, the LIMS, automated liquid handling equipment, pipettes, PCR machines.
- Physical environment, e.g., the designed specimen collection site and laboratory floorplans, required lighting and ventilation, expected noise levels.
- Organization, e.g., shift and team structure, procedures for quality control.
- External environment, e.g., regulation for clinical laboratories from the Centers for Medicare and Medicaid Services (CMS) through the Clinical Laboratory Improvement Amendments (CLIA).

These process maps were developed at varying levels of specificity for use by many stakeholders, including software developers, laboratory technicians, managers and directors, collection site staff, and visualized the flow of specimens, information, waste and work on the floorplans.

The project ultimately resulted in a translatable process for specimen collection, design for a mobile laboratory and a laboratory information management system (i.e., information technology) to support information flow through result delivery. This system was deployed at six sites across the country, serving more than 75 clients, including higher education institutions (e.g., University of Wisconsin-Madison and American University) and major employers (e.g., Bloom Energy, Toyota). These sites performed more than 1 million tests in less than 7 months. Further, the information technology design initiated during the project was refined and deployed in laboratories serving the state of Illinois and the local Champaign-Urbana community.

2.4. Lessons learned

The project was conducted during the second half of 2020. The team was able to conduct in-person observations, but social distancing requirements and the relatively small lab space limited the number of observers and made it difficult to capture details of the work. We had to adapt our observation methodologies to be faster, less resource intensive and minimally intrusive. Ideally, we would have conducted observations with think aloud and interactive questions and taken pictures of the on-campus COVID-19 laboratory and artifacts supporting the technicians there. However, we were not permitted to do so, so observations were conducted by two human factors researchers, who divided foci during the observation – one was focused on process and task, organization and technology, while the other focused on physical environment and tools – to be minimally intrusive and fast (i.e., without think aloud and discussion with workers).

The project team experienced immense time pressure and the subject matter experts experienced heavy workload in the functional laboratory that provided testing for the campus, up to more than 20% of daily tests

in Illinois and 1.5% of daily tests in the United States. As such, we had to pivot away from the idea of a participatory design process involving stakeholders from the on-campus laboratory engaging in simulation and activity redesign in the tradition of constructive ergonomics (cf. Barcellini et al., 2014). Instead, the team relied heavily on input from supervisors and managers, who had a different perception of the work – i.e., task versus activity (Leplat, 1989) – when reviewing our designs. To support their input and participation, the team focused on developing representations of the process and floor plan that were easier to understand quickly, with minimal orientation from HFE analysts, than prior versions of SEIPS-based process models. While the adapted models lack some details captured in the more complex versions, like those developed for care transitions (Wooldridge et al., 2020, 2022), the more accessible versions may ultimately have more impact. It was particularly useful to share the diagrams with software developers to asynchronously support process-oriented LIMS development – the sub-team developing the software was able to understand the diagrams with relatively little input from the HFE sub-team, much as the laboratory supervisors were able to, which helped manage time pressure. A retrospective study to evaluate the impact of the process diagrams on the LIMS development is ongoing.

An important note is that the HFE team did not have an existing relationship or partnership with any of the stakeholders in the laboratory design process, nor the diagnostic laboratory on campus. This meant that HFE team had to work quickly to develop a basic understanding of clinical laboratories and diagnostic processes – much of this was accomplished through reading literature and regulatory guidelines, given aforementioned lack of access to stakeholders due to their workload. The HFE team also spent much time developing relationships, which facilitated more participation in the later phases of the design process (i.e., FMEA and validation of the designs).

Despite of the efforts of the team to gather feedback from stakeholders with experience in the campus lab throughout the design process, there was a negative impact of not being able to spend time with laboratory workers – the plan for the process, floor plan, etc. made sense to the team and the supervisors, but people who worked in the laboratory as technicians very quickly identified issues during the FMEA (e.g., not enough space in the biosafety cabinet, expecting higher reliability in liquid handling equipment than realistic). If the team had access to their expertise earlier in the design project, the design may have converged more quickly and perhaps had better performance.

3. Case 2: Understanding the work system changes during the initial response to the pandemic within the physiotherapy services of one large hospital trust

3.1. Background

Similar to other health care systems worldwide, the National Health Service (NHS), the publicly funded health care system of the UK, underwent extreme changes to the organization and structure of work almost ‘overnight’ at the beginning of 2020. Large numbers of NHS health care staff were redeployed in February 2020 from other health care areas to support the treatment of hospitalised COVID-19 patients (Sykes and Pandit, 2021) and in March 2020 seven NHS Nightingale hospitals (temporary hospitals converted from conference and concert venues) were set up to pre-empt the expected surge in hospitalisations (NHS England, 2020). Despite the extensive changes to daily life, the organizational structure of health care work and the changes brought on by this new patient type, departments and staff across the NHS adapted and developed strategies of coping to keep the health care system functioning.

This unprecedented event resulted in quick adaptations to work occurring across work system levels. These adaptations, namely the system adjusting its operation prior to, during or following changes is an example of organisational resilience as defined by Hollnagel (2011). As

this pandemic is the largest experienced by staff and health care organizations in this generation, the initial response provides information previously unavailable regarding the characteristics of phases of adaptations associated with pandemics, which are necessary for planning response strategies to ensure successful outcomes (Garrett & Caldwell, 2009). Furthermore, the resilience shown during the initial response needs to be understood so that learning can occur, ensuring the transition to embedded organisational resilience instead of individual resilience of staff groups. This would not only assist with protecting staff well-being but would also ensure that appropriate changes to the work system to respond to the pandemic can occur over an extended period of time.

This project was initiated by the Trent Simulation and Clinical Skills Centre (TSCSC) and done in collaboration with the physiotherapy team from the therapy department from one large NHS hospital trust. In April 2020, as part of the NHS hospital trust, the TSCSC team was aware of the rapid organizational changes occurring within the two hospitals that form this trust. With a small in-house HFE team, the centre felt they could offer some unique insight by providing a systems approach and HFE theories to capture and understand the changes occurring, identify learning that could have system-wide implications, and compile recommendations for future waves. At the same time, the senior management of the therapy services were interested in understanding the effects of the new scheduling structure that was implemented in response to the pandemic for future scheduling considerations. The aim of this study was to capture the changes and adaptive ways of working within the physiotherapy service during the initial NHS response to the COVID-19 pandemic in April 2020.

3.2. Methods

A qualitative exploratory approach was adopted using focus groups to explore the changes to the work structure with physiotherapy staff for the period of April to July 2020. In addition to this, the focus groups also explored aspects of tasks that worked more efficiently at the time due to the unusual situation, the strategies the team developed to anticipate and respond quickly to the new situations arising, the current work climate and the current challenges. Eight online focus groups, using Microsoft Teams, were conducted with a total of 26 physiotherapy staff between July and August 2020. The participants included physiotherapy staff from critical care, surgery, medicine and associated specialities, respiratory physiotherapy as well as staff redeployed from outpatients and inpatient elective services such as orthopaedics, whose work had been paused. Each online focus group was approximately 60 min in duration and was recorded.

The audio data from the focus groups were transcribed and analysed using thematic analysis (Braun and Clarke, 2012) with NVivo 11 Software (QSR International Pty Ltd, 2015). The SEIPS 2.0 model (Holden et al., 2013) was used to structure the analysis so that the themes could be placed within the system context from which they emerged. The anonymised results were presented back to staff who participated in the focus groups for sense checking.

3.3. Outcomes

The results identified the changes that had occurred to frontline work for this department, the challenges staff faced during this time, and the aspects that worked well during the initial response to the pandemic. These changes, challenges and facilitators for this work system at this specific time were mapped to identify the connection between these different system elements, using the SEIPS 2.0 model to provide the underlying structure. These results were then used to compile considerations for future waves of this pandemic.

The changes at the different system levels not only caused changes within other system levels, but these created challenges that staff had to overcome and prompted adaptations to maintain the functioning of their

work system. For example, the national change of redeploying staff from non-acute areas (SEIPS 2.0 work system component: external environment) allowed for the change in services provided at this hospital trust and for more extensive operating hours than previously offered by the physiotherapy department (SEIPS 2.0 work system component: organization of work). This resulted in changes to team structure and size (SEIPS 2.0 work system component: organization of work), redistribution of administrative and management work (SEIPS 2.0 work system component: Tasks), and effected space on the wards and in break rooms (SEIPS 2.0 work system component: internal environment). This last aspect was further influenced by the external social change of social distancing (SEIPS 2.0 work system component: external environment), which influenced the number of staff it was safe to have on wards (SEIPS 2.0 work system component: organization of work). The challenges and aspects that worked well that the physiotherapy team identified from the focus groups have been summarized in Table 1.

As this case study was being undertaken, a similar but larger investigation was conducted by the Healthcare Safety Investigation Branch (HSIB) in the UK. The HSIB study collected data from six different hospital trusts through focus groups, observations, interviews, and document analysis. Despite having a slightly different focus and a much broader scope, both studies aimed to identify work system factors associated with treating hospitalised COVID-19 patients using the SEIPS model as a framework for analysis with the aim to compile recommendations. The HSIB report (Healthcare Safety Investigation Branch, 2020) identified some similar themes with regards to challenges experienced by staff. Examples of these included the speed of change regarding guidance, a lack of consistency in the implementation of guidance, PPE-associated challenges, limitations of the work environment relative to the new work requirements, and staff well-being concerns. Some of these barriers have also been mentioned in the systems analysis by Carayon and Perry (2021). Although the HSIB study had a much larger data set and a more extensive analysis, the results from this study only became available two weeks after this project submitted its final report to the Therapy department. This highlights that the TSCSC and physiotherapy teams identified current concerns, not only occurring at their local trust but nationally and decided proactively to explore and compile recommendations to address these concerns in an as timely as possible manner. Furthermore, a key difference between this case and the HSIB study was the availability and access to resources. Despite the limited resources, this study found similar themes and more specifically

Table 1
The challenges and aspects that worked well during the initial response to the COVID-19 pandemic for work within the physiotherapy team listed according to the SEIPS 2.0 components.

Challenges	Aspects that worked well
Tasks: •An increase in administrative work due to the changes in the ways of working.	Tools and Technology: •Development of tools to aid the response to the pandemic (e.g., PPE on-call bags)
Organisation of Work: •Communication problems (e.g., excessive email communication, frequently changing information and guidelines) •Impaired communication and teamwork in PPE. •Inconsistent interpretation of guidance.	Organisation of Work: •Change in work patterns that allowed more efficient working •Enhanced teamwork and structure
Internal Environment: •Space limitations due to increased number of staff due to redeployment and effect of social distancing.	•Localised decision making and enhanced local leadership •Set up of new clinics (e.g., new follow up clinics)
Professional Outcomes: •Staff well-being due to burn out, fatigue and external social pressures.	

highlighted the local challenges and local solutions occurring in this hospital trust. Utilizing this local expertise is one of the key HFE principles defined by Carayon and Perry (2021) for supporting health care system improvement.

3.4. Lessons learned

As the focus of this project was to specifically understand the experiences of staff due to changes in the health care work system resulting from the pandemic, the research design was developed at a time when the project team were already aware of several of the changes to the work environment that may impact data collection. These included the restriction of unnecessary non-clinical staff from the hospital sites, limitation of the number of staff allowed in one room, need for and effect of social distancing and availability of frontline staff to participate.

This project adopted specific strategies with regards to the organization and scheduling of the data collection to mitigate the effect of these restrictions. A key support in the design of the data collection phase for this project, was that a member of the project team was also a clinical staff member who had done extensive work in the participating service. As unnecessary non-clinical staff were restricted from the hospital, any meetings regarding the project including data collection occurred remotely using online tools. This approach had an unexpected benefit, namely as the online meetings provided additional flexibility, which allowed the project to be initiated in an uncharacteristically short amount of time. Furthermore, in the initial design and proposal, the project team decided to run the focus groups at an expected lull, where it was predicted that due to the time of year, the workload would reduce following the initial response to the pandemic (i.e., between June and August).

To address the restriction of staff availability, the focus groups were held during the shift at the hospital sites. However, due to social distancing, the staff rooms had a maximum number of people allowed in one room together. By using online focus groups, the focus groups were organized so that staff at the hospital sites could meet in appropriately sized rooms with access to a device to log on to the online meeting for the focus group; a key member of the project team being a clinical staff member in this service facilitated these arrangements.

Limitations of this project were the format of the feedback to the participants and management of this service; also, the impact of this project was not assessed. From an educational perspective, it may have been more beneficial to create a summary video of the results for participants to view prior to conducting a sense checking session, which ideally would have been done in-person. The results were also presented to management in the form of a traditional project report, just before the next wave commenced. In this context, it may have been more beneficial to create a shorter, more useable document that translated the findings into practical approaches that could be rapidly implemented. The use and need for that type of document has been reflected by the successful uptake of the HFE guides created by the CIEHF on relevant COVID-19 topics.

4. Case 3: HFE application to telemedicine adoption for perioperative pain management

4.1. Background

The opioid crisis continues as opioid addiction and overdose deaths persist (Han et al., 2017). Surgery is a nidus for pain and opioid use (Bicket et al., 2017). In the United States, surgeons account for 1/3 of opioid prescriptions (Levy et al., 2015), and surgical patients have an increased risk of opioid diversion, misuse, and dependency (Brat et al., 2018). The COVID-19 pandemic, while crippling the economic and health care systems and threatening millions of lives, poses significant challenges to pain and opioid management for surgical patients (Alexander et al., 2020). Efforts to prevent the spread of the virus (e.g., social

distancing) can disrupt their care (e.g., maintenance of medications) and limit their access to social supports and medical resources (e.g., physical and occupational therapy, mental health service), which may manifest in increased rates of emergency department visits, hospital admissions, withdrawal symptoms, drug overdoses and diversion, and suicide (Phillips and Nugent, 2014). Telemedicine can potentially address challenges to pain and opioid management during the pandemic (Hollander and Carr, 2020; Lurie and Carr, 2018). However, the adoption of telemedicine is a complex process that can be influenced by various sociotechnical factors (e.g., technology infrastructure, capability and limitations of patients and clinicians, reimbursement).

The Personalized Pain Program (PPP) at the Johns Hopkins Hospital consists of a multidisciplinary team coordinating care for surgical patients throughout the perioperative period (i.e., preoperative consultation, postoperative inpatient hospitalization, postoperative outpatient follow-up) (Hanna et al., 2019). In response to the COVID-19 pandemic, it was decided to adopt telemedicine to continuously provide care for its patients. PPP clinicians had collaborated with the HFE team from the Johns Hopkins Armstrong Institute for Patient Safety and Quality on several projects to improve the quality and safety of perioperative pain management using an HFE approach. Recognizing the importance of HFE to health care quality and safety, they engaged the HFE team to help facilitate the transition of the clinic to telemedicine.

4.2. Methods

For the previous projects, the HFE team had conducted extensive observations of in-person PPP visits and a number of interviews with PPP patients and clinicians to understand the clinical workflow prior to the pandemic. Based on findings from the observations and interviews and guided by the SEIPS 2.0 model (Holden et al., 2013), the team worked with different stakeholders (e.g., leadership, IT experts, clinicians, patients) through virtual individual and/or group meetings to proactively identify challenges to telemedicine adoption and adapt different elements of the PPP work system.

Beginning March 23, 2020, one week after the Secretary of Health and Human Services modified telemedicine requirements (Public Health Emergency, 2020), telemedicine was implemented in the PPP; in-person PPP visits were restricted. To continuously improve the use of telemedicine, the team adapted their data collection tools and procedures and conducted additional observations of telemedicine PPP visits and interviews with PPP clinicians and patients through the telemedicine platform. In addition, data on opioid consumption and patient outcomes (e.g., pain severity and interference, satisfaction, perceived engagement) were continuously collected by chart review and patient surveys to assess the impact of telemedicine on the quality and safety of perioperative pain management.

4.3. Outcomes

To facilitate the implementation of telemedicine, different elements of the PPP work system were adapted, including:

- People, e.g., clinicians receiving authorization to electronically prescribe controlled substances, clinical coordinator trained in establishing telemedicine platform with patient, patients receiving instructions on how to install and launch telemedicine platform;
- Tasks, e.g., clinical coordinator obtaining patient consent to telemedicine visit and confirming patient access to telemedicine platform before visit, clinician completing history and modified physical exam during visit, patient receiving summary in electronic medical records after visit;
- Tools and technology, e.g., HIPAA compliant platform for telemedicine visits, non-HIPAA compliant platforms for telemedicine as needed;

- Physical environment, e.g., patient and clinician joining from home; and
- Organization, e.g., guidance on using (non-)HIPAA compliant telemedicine platforms (Rahman et al., 2020).

The implementation of telemedicine did not significantly influence the monthly number of new patients participating in the PPP and their demographic and clinical characteristics (e.g., age, gender, race, type of surgery, history of opioid use). Improvement in daily opioid consumption, pain severity and interference, satisfaction with the PPP, and perceived patient engagement was observed in both patients with only in-person PPP visits and patients with only telemedicine PPP visits. Compared to patients with only in-person PPP visits, patients with only telemedicine visits had greater reduction in pain severity and higher satisfaction and perceived engagement during first PPP.

Both PPP clinicians and patients were satisfied with the use of telemedicine, which helped overcome many challenges faced by PPP patients (e.g., immobility due to postoperative conditions, lengthy travel times, lack of access to transportation, inconvenience of parking at the hospital, apprehension of exposure to COVID-19). While some disadvantages of telemedicine were noticed (e.g., less personal, technical difficulties with setting-up the telemedicine platform, challenges to conducting physical exams, it was suggested to be integrated as a routine practice of the PPP beyond the pandemic).

4.4. Lessons learned

In this project, an HFE approach was applied to facilitate the adoption of telemedicine for perioperative pain management during the COVID-19 pandemic. The work was based on an established partnership between the clinicians and the HFE team and the preliminary data collected by the HFE team before the pandemic, which were essential to the successful application of HFE to a timely response to the pandemic.

The HFE approach involved substantial efforts to collect observation and interview data in “the field.” Because of the pandemic, the team rapidly adapted their data collection tools and procedures to shift from in-person to virtual observations and interviews. The change of the data collection mode limited the data that could be obtained. For example, observing through the telemedicine platform could hardly capture the real home environment in which patients had their telemedicine visits. The team, therefore, had to rely more on the interviews to understand the home environment described by the patients.

The HFE approach also emphasized the participation of different stakeholders in the implementation of telemedicine and the adaptation of the work system, which was facilitated by the widespread use of virtual meetings during the pandemic. However, the effectiveness of virtual meetings might be suboptimal as compared to in-person meetings. Innovative strategies were needed to support multi-stakeholder collaboration using virtual meetings.

5. Opportunities going forward

As demonstrated by the three cases, and aligning with the body of literature describing applications of HFE to support responses to the COVID-19 pandemic (e.g., Gurses et al., 2020; Salmon et al., 2021), HFE can have immense impact and support work and the people working during pandemics. Each case provided a different example of the role HFE can play in health care during a pandemic and how this work can be achieved in a short time. The first case focused on supporting work associated with detecting and monitoring the disease causing the pandemic, the second supported organizational learning by understanding the effect of the changes in the different work system levels and the experience of frontline staff, and the third facilitated the modification of a care process to mitigate the restrictions created by the pandemic. However, in each of the projects, we faced and adapted to unique challenges posed by responding to urgent, time-sensitive

emergencies. The limitations and effects of the pandemic on the HFE cases, as well as the modifications made in each case, have been summarized in Fig. 1.

Our experiences highlighted the need for modifications to existing strategies and methods within HFE and for new approaches to address three interacting observations that spanned the three cases, described in Fig. 1.

First, HFE methods and dissemination tend to be resource intensive and/or require in-person interaction that may not be feasible in a crisis – for example, Cases 1 and 3 involved conducting observations of work while Case 2 included focus groups and member-checking sessions. In each case, the research teams adapted HFE methodologies to account for these restrictions: in Case 1, observers were limited and did not interact with workers while other data sources (e.g., document review) helped to fill gaps; in Case 2, sessions were conducted virtually and organized to leverage prior knowledge of the facility, staff schedule and expected case load; in Case 3, meetings and observations were conducted virtually and additional data collection method (i.e., interviews, surveys, chart review) were used to supplement findings. One important note is that quick dissemination to enhance learning at multiple levels, including specific sites, organizations and the HFE discipline, were lacking across the cases and could inform such adaptations under time pressure in the future.

Second, an existing relationship between HFE experts and stakeholders facilitated quick, useful responses in Cases 2 and 3. In Case 2, for example, the HFE team had good insights into timeframes that were convenient for stakeholders to conduct virtual meetings and had a clinical partner that could help identify suitable rooms for participants on site. In Case 3, the HFE team was able to leverage previously collected data to inform the redesign of work in real time when adapting telemedicine due to the pandemic. However, in Case 1 the HFE team did not have prior relationships with the stakeholders involved in the laboratory design process, to negative effect – access to interact with workers was restricted until interactions to establish trust with laboratory management had taken place, in addition to the team having limited background, domain knowledge about biomolecular laboratories. Increasing the quantity and prevalence of HFE experts working in domains involved in response to public health crises could help to develop these important relationships for future.

Lastly, all three of these projects came about because individuals and groups involved in response to the COVID-19 pandemic recognized the importance of HFE to those responses. In Case 1, university administration charged the HFE team to lead this particular project, adapting and translating technology developed in other pandemic response efforts, due to their experience in health care settings and designing and evaluating processes, albeit after the HFE team had raised the idea to unit leaders at the university. In Case 2, the HFE team actually reached out and proposed the project to the Physiotherapy department at their own hospital trust – they worked with the department before and leadership agreed the project was necessary. In Case 3, the HFE team was actively collaborating with the clinical team already; when it became clear that the adoption and integration telemedicine in the clinic would be required, the clinical team requested the HFE team to help them plan and evaluate the implementation. One overarching commonality, beyond the aforementioned existing relationships in Case 2 and 3, is that a leader in a response effort recognized the importance of HFE in the response. Outreach to position HFE as a cornerstone of emergency and crisis response could lead to broader recognition and integration in future responses.

In the following sections, we discuss strategies and opportunities in line with these three observations that could better support HFE contributions to public health emergencies, like the COVID-19 pandemic, in the future.

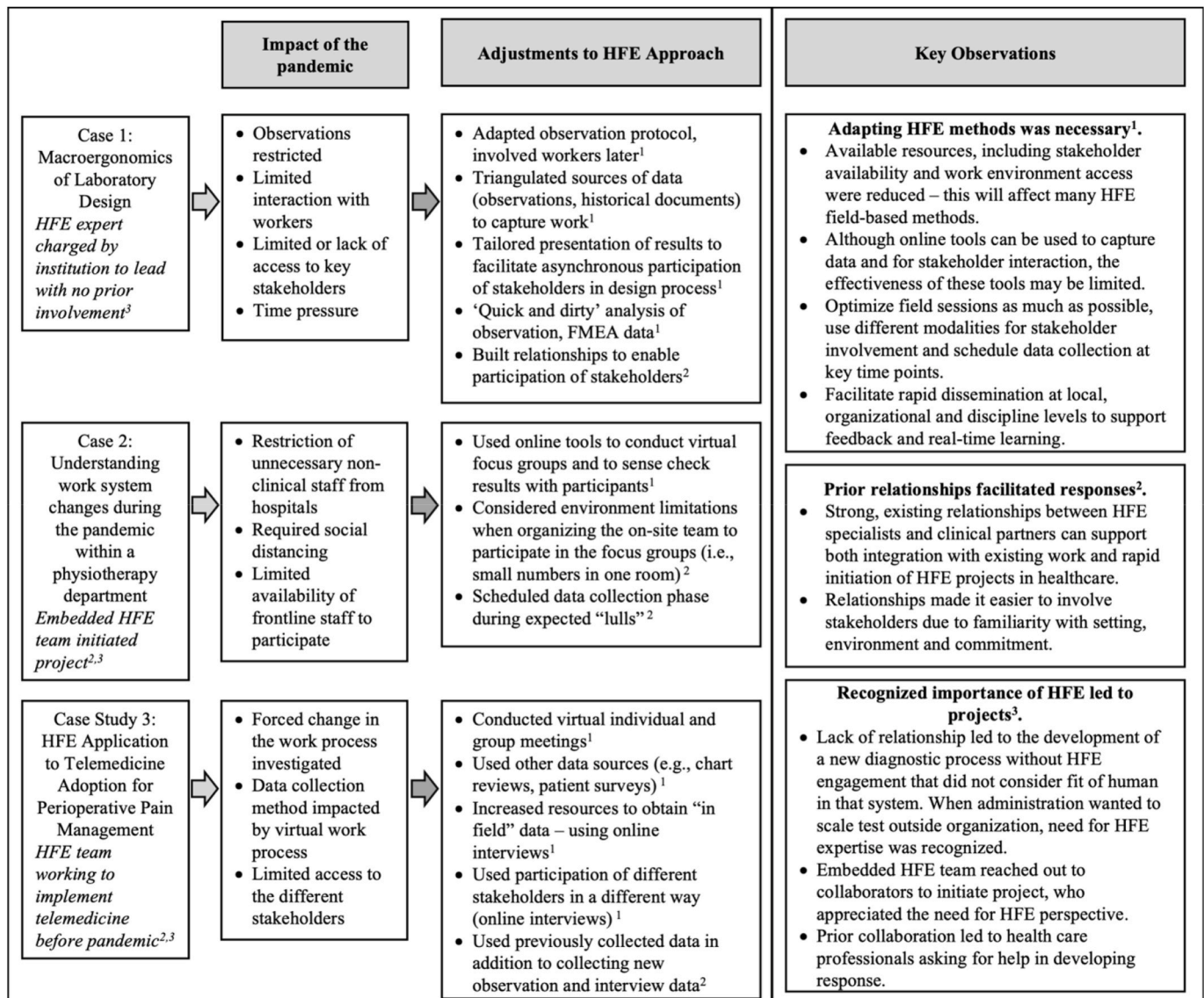


Fig. 1. Summary of impact of pandemic, required modifications to HFE approach and observations. The superscript numbering in note of how project was initiated and adjustments to HFE approach link show linkages from case studies to key observations.

5.1. Adaptations to HFE methods and dissemination

A key effect of the pandemic, identified across all three cases, was the restricted access to the work environment and the people in the system. As most field-based HFE methods rely on HFE analysts spending time in the field, many of these methods were not feasible (Mallam et al., 2021). For example, in Case 1 visitors were restricted from COVID-19 laboratories, in Case 2 the project team were unable to hold the focus groups in-person in the hospital and in Case 3 in-person observations and interviews were limited after telemedicine adoption. In other words, we were either entirely unable to conduct “normal” data collection methods or were significantly limited in what could be conducted. This restriction limited the data that could be captured and the variety of data collection methods we could employ. We responded with innovative ways to mitigate these limitations, including optimizing the observation sessions one could conduct, planning the timing of the data collection, greater stakeholder involvement and the involvement of key stakeholders in other elements of the project. For example, in the laboratory design project (Case 1), some observations were possible, so the team carefully prepared and prioritized which data to capture to minimize the number of observations needed and relied more on feedback from supervisors

and managers to fill gaps; this was not ideal due to differences between task and activity (i.e., work-as-imagined versus work-as-done) (Hollnagel et al., 2006; Leplat, 1989). As a result of the restricted access to the work system and people within it, the timing of data collection has become even more important, as was shown in Cases 1 and 2. In Case 1, the team compensated by involving laboratory technicians in proactive risk assessment and validation studies conducted during a period of less activity when their availability improved, and restrictions were loosened. Similarly in Case 2, the focus groups were held at a time when it was expected that the work system would experience a lull in workload, while still being close enough that the events were fresh in staff’s memories.

One of the approaches to mitigate the effect of the pandemic on HFE projects and work in health care was related to the modality of participation and collaboration with stakeholders. Due to pandemic restrictions and burgeoning workload, organizing synchronous, co-located meetings became challenging – the use of virtual meetings made it easier for different stakeholders to participate, as seen in Cases 2 and 3. These online meetings and focus groups allowed the team to circumvent numerous effects of the restrictions in place, as well as allowing rapid project initiation and capturing extensive discussions on staff’s

experience of the pandemic at a relevant point in time. This format limited the feedback the team could provide later in the project, and, from educational perspective, it would have been better to have feedback the results in-person. Although online technologies may provide a useful tool, a balance needs to be found with careful consideration for when a face-to-face session may be more appropriate. An additional question arose, namely how could we facilitate multi-stakeholder collaboration when in-person communication is limited?

These modifications to data collection methods we rely on regularly, outside of the COVID-19 pandemic, were necessary to accomplish our project goals. However, we believe these adaptations may be instrumental in furthering, broadening and deepening the impact of the science of HFE during and outside of crises. For example, while HFE is acknowledged as crucial to improving patient safety, integration of HFE in health care systems has been slow (Carayon et al., 2018). Adapting our methods to facilitate deep, meaningful participation of stakeholders (e.g., clinicians), with a smaller demand on their time, will not only facilitate fast response during crises; it will also support our “regular” work. Adapting our methods to support distributed work – when an HFE analyst cannot be in the field, or when a stakeholder cannot participate in-person – will increase our geospatial reach. Further, these methodological innovations could incorporate and contribute to the call to develop systems ergonomics methods truly appropriate for the complex systems involved in societal issues and global problems (Salmon et al., 2019; Thatcher et al., 2018, 2020).

5.1.1. Facilitating rapid dissemination

At the 2021 Triannual Congress of the International Ergonomics Association there were nine sessions with 36 talks focused on COVID-19 and a further 14 talks with COVID-19 in the title but in other sessions – however, this meeting was held 15 months after the World Health Organization declared the COVID-19 pandemic. Clearly, many HFE experts were working on projects to support response efforts, alone or in groups. As individuals working on projects, we believe our efforts and that of our peers would have benefitted with earlier sharing of approaches and preliminary findings. While there were webinars and papers focused specifically on health care, as well as exemplary resources organized by the CIEHF, an alternative, perhaps more expedient, publication process for journals and even proceeding papers may facilitate faster sharing of expertise and ideas. For example, HFE journals could develop processes to identify manuscripts related to specific, dynamically changes and critical situations; these manuscripts could then be reviewed rapidly. Another example could be to adopt alternative formats for publications, outside of the traditional research paper, such as letters, viewpoint papers and short reports. These could also be made available as open access to support further dissemination; for example, every article in the special issue of *Human Factors and Ergonomics in Manufacturing and Service Industries* was published as free or open access.

As we move forward, these guiding questions (i.e., how can we reduce the resources required for HFE methods? How can we conduct deep work with less, or even no, time in-person? How can we support just-in-time sharing of methods, foci and findings?) should drive individual and collective reflection to further the impact of our science. We acknowledge that potential concern of developing and adopting “quick and dirty” methods and dissemination comes with potential challenges to rigor. Rigor is of course paramount; we argue that rigor is crucial in quick response to crisis – a misstep could not only lose the trust of key partners but could also spell disaster in terms of loss of life or livelihoods. Therefore, ensuing reflection and action must also attend to rigor.

5.2. Increasing available HFE expertise to build more relationships

One challenge that our field faces is related to the number of available HFE experts in health care organizations and the preparation required by our discipline – in short, we believe our field should grow so

that we have a larger number of properly-prepared individuals to participate in and/or lead crisis responses – Salmon et al. (2021) suggest potential HFE contributions may be overlooked; we posit that an additional challenge is the size of our profession, in addition to recognition, described in section 5.3. While we are seeing a growing number of programs focused on HFE at higher education institutions, we hope that the HFE discipline can broaden participation by attracting a diverse group of future experts, perhaps by engaging in outreach to students before entry to a university or college (Spiwak et al., 2021). Another idea is to proactively embed HFE as a component, rather than focus, of education programs. For example, engineers – who apply science and mathematics to design or develop solutions for humanity – may benefit from a required HFE course. Another example would be to include HFE in patient safety and quality improvement education that is already embedded in most health care curricula (Vosper et al., 2018). In this case, we expect that those designs or quality improvement projects may better support human well-being and system performance (i.e., the central goal of HFE) without an HFE expert, in “normal” work as well as during crisis response. Similarly, our field should attempt to spread our systems perspective to other domains and fields; our professional societies may be well positioned to spearhead broader efforts, but individuals could also attempt to foster local, grassroots change. Case 2 provided an opportunity to share with frontline staff a means of understanding the changes in the work system and how it may affect their work and well-being. The pandemic highlighted specific examples of system effects on frontline staff, as decisions made at a national level filtered down and changed work on the frontline rapidly. Staff not only experienced rapid changes to their work, but also the effect on their well-being. The pandemic has magnified the importance of system considerations on work and staff well-being in a much shorter time frame, making it tangible and readily acceptable to individuals outside the HFE field, if we can provide them with a lens or framework to see the connections within the work system. The SEIPS model can serve as such a framework, highlighting hard to see features of the complex systems in health care (Carayon and Perry, 2021).

We previously highlighted the resource-intensive nature of our methods, but we did not highlight the significant preparation (i.e., post-baccalaureate education) required to complete the activities highlighted in our cases, all led by PhD-prepared experts. As we adapt our methodologies, we might consider modifications to suit practitioner needs versus those of academics. If we can also develop methods that do not require graduate training in HFE, the pool of individuals who can contribute to holistic, human-centered work will grow exponentially. A series of white papers tailored to different scenarios that include guidelines could be a nice collection to make available with the above toolbox; the recent SEIPS 101 paper by Holden and Carayon (2021) may be a useful example, as well as those resources from CIEHF. An additional example of a project working towards providing an HFE toolkit for non-experts and online resources on HFE tools and theories for health care staff is the project “Community of Practice: Human Factors and Quality Improvement” (Q Exchange, 2020). Furthermore, HFE experts often need to “boot strap” and gather background knowledge about a new domain; this posed a significant challenge in the Case 1, where Dr. Woolldridge had not worked in a diagnostic laboratory. Developing a set of guidelines or practices to hasten this uptake could be beneficial.

5.3. Promotion and integration of HFE in crisis response

The pandemic, as a humanitarian crisis, saw many individuals wanting to help as much as possible and wherever one could. As a science, HFE has several fundamental principles that position it to assist in the response to the pandemic (i.e., systems perspective, stakeholder involvement) and it is not surprising that many in our field sought and found opportunities to help. Due to the uncertain and novel situation the pandemic created, HFE experts may have felt more able to speak up and offer services to assist with the situation. For example, Case 2 was

initiated as a project because the HFE team approached the therapy department with a proposal that aligned with a concern of management. Another example was the proactive and rapid production of guidance documents on how HFE could support work and the response to the pandemic by the CIEHF. However, one ongoing opportunity is to establish external recognition of the importance of HFE in responses to global threats to humanity (Salmon et al., 2019; Wooldridge, 2021).

The cases show that projects could be initiated more efficiently where an existing trusted partnership existed between the HFE team and departments. In Cases 2 and 3, the trusted partnership with clinical staff aided the process and allowed for the more rapid initiation of the projects. In Case 3, it was because of the trusted partnership that the clinical group approached the HFE team for support. In comparison, Case 1 came about because the need for HFE knowledge was recognized at the leadership level, and the lack of trusting partnerships impeded the project initially.

HFE experts may not always “be on the list of experts to call,” perhaps due to the lack of integration of HFE in health care systems, partnerships with the different clinical groups, or a limited understanding of the wide range of what HFE can offer work systems. Further, the benefits of HFE may not be immediately visible or measurable. As a result, as HFE experts we need to be ready and willing to “sell our wares,” engaging in outreach about how and why our expertise is needed, something the HFE community may have been more proactive at during the pandemic. We need to develop the evidence base of how HFE can and should help for future, including how to promptly adapt processes (including our own) to rapidly changing work environments as occurred during the pandemic.

6. Additional considerations: Re-Balancing the HFE focus on crisis response by attending to burnout and workload

A problem across domains, due in part to increased personal and professional demands during the pandemic, is occupational stress, well-being and burnout. HFE has a rich history of contributing to this body of knowledge (e.g., Carayon, 1994). However, in compiling our cases and reviewing the work presented at the IEA Triannual Congress, we noted that the predominant focus was on maintaining system functioning. As the pandemic has progressed, the effect on staff well-being is emerging more strongly now, and we need to rebalance our focus so that system functioning is being maintained while managing worker workload, stress and burnout, which may be from the strong initial response to the pandemic. In retrospect, our response was natural: in some sense, we were in survival mode. How could the clinicians we aim to support continue to provide care? How could we increase equitable access to diagnostic testing? Our overarching goal – to keep our society healthy – was admirable. But moving forward the initial response must be to improve (or at the very least, not exacerbate) well-being and burnout while we find ways to keep the system going. In an interesting turn of events, if we sell our HFE wares more effectively, even if we reduce the resources needed and increase the available expertise, we may soon be concerned for the well-being and burnout levels of HFE experts. At the very least, we urge current HFE experts who have, are and will engage in COVID-19 response to explicitly explore and mitigate issues related to well-being and burnout of those they support (e.g., clinicians) and of themselves.

7. Conclusion

In this paper, we presented three examples of HFE-led projects that contributed to COVID-19 response efforts by targeting different work systems, spreading the impact of our profession during an unprecedented pandemic. These three projects had important, real-life impact – demonstrating that HFE can and should be involved in crisis response. We highlighted different methods applied and the challenges we overcame in those projects, namely current HFE methods are resource

intensive and require substantial training and expertise to execute. As a discipline, we need to adapt our tools and methods, increase available expertise and increase awareness of our role in crisis response. We have posed several questions and suggestions to increase the prevalence and impact of HFE during response to crises, like pandemics.

Declaration of competing interest

The 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.

Case 1. Funding was provided by the University of Illinois System. The authors would like to thank all members of the project team, in particular Harley Johnson, Richard Fredrickson, Kirstin L. Dohrer, Vanessa Revindran-Stam and Christopher Pond.

Case 2. The authors would like to thank the rest of the TSCSC team, Giulia Miles and Laura Evans, that worked on this project. Also thank you very much to the therapy department and all the staff that participated in this study.

Case 3. The work is supported by a grant from the US Centers for Disease Control and Prevention (grant number: R01CE003150). The authors would like to thank all members of the study team, in particular Drs. Marie Hanna, Ronen Shechter, Traci Speed, Eileen McDonald, Jill Marsteller, Ayse Gurses, and Yea-Jen Hsu.

Acknowledgements

The authors would like to thank Jennie Jackson for her thoughts and support of initiating this paper.

References

- Adam, C., Bengler, K., 2021. It Takes Two to Tango: Communication at Work during the COVID-19 Pandemic. Congress of the International Ergonomics Association.
- Alaminos-Torres, A., Martínez-Lorca, M., Sifre De Sola, I., López-Ejeda, N., Dolores Marrodán, M., 2021. Psychological distress in Spanish airline pilots during the aviation crisis caused by the COVID-19 pandemic and psychometric analysis of the 12-item general health questionnaire. *Ergonomics*. <https://doi.org/10.1080/00140139.2021.1984587>.
- Alexander, G.C., Stoller, K.B., Haffajee, R.L., Saloner, B., 2020. An epidemic in the midst of a pandemic: opioid use disorder and COVID-19. *Ann. Intern. Med.* 173 (1), 57–58. <https://doi.org/10.7326/M20-1141>.
- Arcuri, R., Bellas, H.C., Ferreira, D.d.S., Bulhões, B., Vidal, M.C.R., Carvalho, P.V. R.d., Jatobá, A., Hollnagel, E., 2022. On the brink of disruption: applying Resilience Engineering to anticipate system performance under crisis. *Appl. Ergon.* 99 <https://doi.org/10.1016/j.apergo.2021.103632>, 103632–103632.
- Ayyildiz, E., Taskin Gumus, A., 2021. A Novel Distance Learning Ergonomics Checklist and Risk Evaluation Methodology: A Case of Covid-19 Pandemic. *Human Factors and Ergonomics in Manufacturing & Service Industries*.
- Barcellini, F., Van Belleghem, L., Daniellou, F., 2014. Design projects as opportunities for the development of activities. *Constructive ergonomics* 150–163.
- Beh, S.F., Holdik, E.N., Bin, Y.S., Cheung, J.M.Y., 2021. Air Travellers' Experiences and Understanding of Jetlag and Perceptions of Management Strategies: a Qualitative Study. *Ergonomics*. <https://doi.org/10.1080/00140139.2021.1980112>.
- Bentley, T., Green, N., Tappin, D., Haslam, R., 2020. State of science: the future of work – ergonomics and human factors contributions to the field. *Ergonomics* 64 (4), 427–439. <https://doi.org/10.1080/00140139.2020.1841308>.
- Bicket, M.C., Long, J.J., Pronovost, P.J., Alexander, G.C., Wu, C.L., 2017. Prescription opioid analgesics commonly unused after surgery: a systematic review. *JAMA Surg* 152 (11), 1066–1071. <https://doi.org/10.1001/jamasurg.2017.0831>.
- Brat, G.A., Agniel, D., Beam, A., Yorkgitis, B., Bicket, M., Homer, M., Fox, K.P., Knecht, D. B., McMahaill-Walraven, C.N., Palmer, N., Kohane, L., 2018. Postsurgical prescriptions for opioid naive patients and association with overdose and misuse: retrospective cohort study. *BMJ* 360, j5790. <https://doi.org/10.1136/bmj.j5790>.
- Braun, V., Clarke, V., 2012. In: Thematic Analysis. American Psychological Association, pp. 57–71.
- Brusaca, L.A., Barbieri, D., Mathiassen, S.E., Holtermann, A., Oliveira, R.V., Oliveira, A. B., 2021. Effects of Working from Home during the Covid-19 Pandemic on Physical Behaviors Among Office Workers in Brazil, p. IEA2021.
- Carayon, P., 1994. Stressful jobs and nonstressful jobs: a cluster analysis of office jobs. *Ergonomics* 37 (2), 311–323.
- Carayon, P., 2006. Human factors of complex sociotechnical systems. *Appl. Ergon.* 37 (4), 525–535. <https://doi.org/10.1016/j.apergo.2006.04.011>.

- Carayon, P., Perry, S., 2021. Human factors and ergonomics systems approach to the COVID-19 healthcare crisis. *Int. J. Qual. Health Care* 33 (Suppl. 1). <https://doi.org/10.1093/INTQHC/MZAA109>, 1-1.
- Carayon, P., Woolldridge, A.R., Hose, B.-Z., Salwei, M., Bennenyan, J., 2018. Improving patient safety through human factors and systems engineering: experiences, opportunities and challenges. *Health Aff.* 37 (11).
- Carayon, P., Woolldridge, A.R., Hoonakker, P., Hundt, A.S., Kelly, M.M., 2020. Seips 3.0: human-centered design of the patient journey for patient safety. *Appl. Ergon.* 84, 103033. <https://doi.org/10.1016/j.apergo.2019.103033>.
- Carman, E.-M., Evans, L., Miles, G., 2021. Learning about Healthcare Resilience from the Initial Response to the COVID-19 Pandemic – A Physiotherapy Case Study. *Lecture Notes in Networks and Systems* Congress of the International Ergonomics Association.
- CIEHF. Covid-19 – Human factors where it's needed most (n.d.), Retrieved January 25, 2022 from. <https://covid19.ergonomics.org.uk/>.
- de Winter, J.C.F., Hancock, P.A., 2021. Why human factors science is demonstrably necessary: historical and evolutionary foundations. *Ergonomics* 64 (9), 1115–1131. <https://doi.org/10.1080/00140139.2021.1905882>.
- Dillon, K., Hiemstra, M., Mitchell, M., Bartmann, N., Rollo, S., Gardiner, P.A., Prapavessis, H., 2021. Validity of the occupational sitting and physical activity questionnaire (OSPAQ) for home-based office workers during the COVID-19 global pandemic: a secondary analysis. *Appl. Ergon.* 97 <https://doi.org/10.1016/j.apergo.2021.103551>, 103551-103551.
- Dul, J., Bruder, R., Buckle, P., Carayon, P., Falzon, P., Marras, W.S., Wilson, J.R., van der Doelen, B., 2012. A strategy for human factors/ergonomics: developing the discipline and profession. *Ergonomics* 55 (4), 377–395. <https://doi.org/10.1080/00140139.2012.661087>.
- Edwards, K., Jensen, P.L., 2014. Design of systems for productivity and well-being. *Appl. Ergon.* 45 (1), 26–32.
- Exchange, Q., 2020. Community of Practice: Human Factors (HF) & Quality Improvement (QI). <https://q.health.org.uk/idea/2019/community-of-practice-human-factors-hf-quality-improvement-qi/>.
- Garrett, S.K., Caldwell, B.S., 2009. Human Factors Aspects of Planning and Response to Pandemic Events.
- Godoy, L.d., Ferreira, M.G.G., Robertson, M.M., 2021. COVID-19 and Teleworking from Home: Understanding New Issues from a Macroergonomic Perspective. *Congress of the International Ergonomics Association*.
- Goggins, K.A., Tetzlaff, E.J., Young, W.W., Godwin, A.A., 2022. SARS-CoV-2 (Covid-19) workplace temperature screening: seasonal concerns for thermal detection in northern regions. *Appl. Ergon.* 98 <https://doi.org/10.1016/j.apergo.2021.103576>, 103576-103576.
- González, C., Rodríguez, L.L., Fonte, D.M., González, A.G., Gomes, J.O., 2021. Government Strategies in the Confrontation of Covid-19 in the Republic of Cuba. *Congress of the International Ergonomics Association*.
- Griebel, H.R., Smith, T.J., 2021. University Student Experiences with Mandated Home Isolation. *Congress of the International Ergonomics Association*.
- Gulotta, C.J., Madeira-Revell, K., Fendley, M.E., 2021. A Heuristic International Glimpse at SARS-CoV-2 Effects on Work-home Equilibrium and Women. *Human Factors and Ergonomics in Manufacturing & Service Industries*.
- Gurses, A.P., Tschudy, M.M., McGrath-Morrow, S., Husain, A., Solomon, B.S., Gerohistodoulos, K.A., Kim, J.M., 2020. Overcoming COVID-19: what can human factors and ergonomics offer? *J. Patient Safety Risk Manag.* 25 (2), 49–54. <https://doi.org/10.1177/2516043520917764>.
- Hale-Lopez, K.L., Woolldridge, A.R., Goldstein, M.H., 2021. Using technology to support distributed teams: a work system-based study of an interdisciplinary team responding to COVID-19. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* 65 (1), 174–178. <https://doi.org/10.1177/1071181321651062>.
- Han, B., Compton, W.M., Blanco, C., Crane, E., Lee, J., Jones, C.M., 2017. Prescription opioid use, misuse, and use disorders in U.S. Adults: 2015 national survey on drug use and health. *Ann. Intern. Med.* 167 (5), 293–301. <https://doi.org/10.7326/M17-0865>.
- Hanna, M.N., Speed, T.J., Shechter, R., Grant, M.C., Sheinberg, R., Goldberg, E., Campbell, C.M., Theodore, N., Koch, C.G., Williams, K., 2019. An innovative perioperative pain program for chronic opioid users: an academic medical center's response to the opioid crisis. *Am. J. Med. Qual.* 34 (1), 5–13. <https://doi.org/10.1177/1062860618777298>.
- Healthcare Safety Investigation Branch, 2020. COVID-19 Transmission in Hospitals: Management of the Risk - a Prospective Safety Investigation. <https://www.hsib.org.uk/investigations-and-reports/covid-19-transmission-in-hospitals-management-of-the-risk/covid-19-transmission-in-hospitals-management-of-the-risk-a-prospective-safety-investigation/>.
- Heiden, M., Hallman, D., Svensson, S., Mathiassen, S.E., Bergström, G., 2021. Productivity, Well-Being and Work-Family Conflict in Mandatory Telework during the COVID-19 Pandemic. June, Vancouver, Canada, pp. 14–18. IEA 2021.
- Hendrick, H.W., 1996. The ergonomics of economics is the economics of ergonomics. *Proc. Hum. Factors Ergon. Soc. Annu. Meet.* 40 (1), 1–10. <https://doi.org/10.1177/154193129604000101>.
- Hignett, S., Carayon, P., Buckle, P., Catchpole, K., 2013. State of science: human factors and ergonomics in healthcare [Journal Article]. *Ergonomics* 56 (10), 1491–1503. <https://doi.org/10.1080/00140139.2013.822932>.
- Hignett, S., Edmonds, J., Herlihey, T., Pickup, L., Bye, R., Crumpton, E., Suján, M., Ives, F., Jenkins, D.P., Newbery, M., 2021. Human factors/ergonomics to support the design and testing of rapidly manufactured ventilators in the UK during the COVID-19 pandemic. *Int. J. Qual. Health Care* 33 (Suppl. ment_1), 4–10.
- Holden, R.J., Carayon, P., 2021. SEIPS 101 and Seven Simple SEIPS Tools. *BMJ Quality & Safety*. <https://doi.org/10.1136/bmjqs-2020-012538> bmjqs-2020-012538.
- Holden, R.J., Carayon, P., Gurses, A.P., Hoonakker, P., Hundt, A.S., Ozok, A.A., Rivera-Rodriguez, A.J., 2013. Seips 2.0: a human factors framework for studying and improving the work of healthcare professionals and patients. *Ergonomics* 56 (11), 1669–1686. <https://doi.org/10.1080/00140139.2013.838643>.
- Hollander, J.E., Carr, B.G., 2020. Virtually perfect? Telemedicine for covid-19. *N. Engl. J. Med.* 382 (18), 1679–1681. <https://doi.org/10.1056/NEJMp2003539>.
- Hollnagel, E., 2011. Prologue: the Scope of Resilience Engineering xxix-xxxix. http://www.gowerpublishing.com/pdf/SamplePages/Resilience_Engineering_in_Practice_Prof.pdf.
- Hollnagel, E., Woods, D.D., Leveson, N. (Eds.), 2006. *Resilience Engineering - Concepts and Precepts*. Ashgate.
- 9241-210 ISO, 2019. 2019: Ergonomics of Human-System Interaction — Part 210: Human-Centred Design for Interactive Systems. International Organization for Standardization (ISO), Switzerland.
- Janson, D.J., Clift, B.C., Dhokia, V., 2022. PPE fit of healthcare workers during the COVID-19 pandemic. *Appl. Ergon.* 99 <https://doi.org/10.1016/j.apergo.2021.103610>, 103610-103610.
- Keller, S.C., Pau, S., Salinas, A.B., Oladapo-Shittu, O., Cosgrove, S.E., Lewis-Cherry, R., Vecchio-Pagan, B., Osei, P., Gurses, A.P., Rock, C., 2021. Barriers to physical distancing among healthcare workers on an academic hospital unit during the coronavirus disease 2019 (COVID-19) pandemic. *Infect. Control Hosp. Epidemiol.* 1–7.
- Kelly-Cirino, C.D., Nkengasong, J., Kettler, H., Tongio, I., Gay-Andrieu, F., Escadafal, C., Piot, P., Peeling, R.W., Gadde, R., Boehme, C., 2019. Importance of diagnostics in epidemic and pandemic preparedness. *BMJ global health* 4 (Suppl. 2), e001179. <https://doi.org/10.1136/bmjgh-2018-001179> e001179.
- Leplat, J., 1989. Error analysis, instrument and object of task analysis. *Ergonomics* 32 (7), 813–822.
- Levy, B., Paulozzi, L., Mack, K.A., Jones, C.M., 2015. Trends in opioid analgesic-prescribing rates by specialty, U.S., 2007–2012. *Am. J. Prev. Med.* 49 (3), 409–413. <https://doi.org/10.1016/j.amepre.2015.02.020>.
- Lieberman-Cribbin, W., Tuminello, S., Flores, R.M., Taioli, E., 2020. Disparities in COVID-19 testing and positivity in New York city. *Am. J. Prev. Med.* 59 (3), 326–332. <https://doi.org/10.1016/j.amepre.2020.06.005>.
- Lurie, N., Carr, B.G., 2018. The role of telehealth in the medical response to disasters. *JAMA Intern. Med.* 178 (6), 745–746. <https://doi.org/10.1001/jamainternmed.2018.1314>.
- Mallam, S.C., Nordby, K., Haavardtun, P., Nordland, H., Viveka Westerberg, T., 2021. Shifting participatory design approaches for increased resilience. *IISE Trans. Occup. Ergonom. Human Factors* 1–8.
- Mumma, J.M., Jordan, E., Ayeni, O., Kaufman, N., Wheatley, M.J., Grindle, A., Morgan, J., 2022. Development and validation of the discomfort of cloth Masks-12 (DCM-12) scale. *Appl. Ergon.* 98 <https://doi.org/10.1016/j.apergo.2021.103616>, 103616-103616.
- National Center for Immunization and Respiratory Diseases (U.S.) Division of Viral Diseases, 2020. Interim Laboratory Biosafety Guidelines for Handling and Processing Specimens Associated with Coronavirus Disease 2019. *COVID-19*.
- Naweed, A., Jackson, J.E., Read, G.J.M., 2021. Ghost trains: Australian rail in the early stages of the global COVID-19 pandemic. *Human Factors Ergon. Manufact. Service Indus.* 31 (4), 438–444. <https://doi.org/10.1002/hfm.20886>.
- NHS England, 2020. NHS England » NHS Steps up Coronavirus Fight with Two More Nightingale Hospitals. <https://www.england.nhs.uk/2020/04/nhs-steps-up-coronavirus-fight-with-two-more-nightingale-hospitals/>.
- Phillips, J.A., Nugent, C.N., 2014. Suicide and the Great Recession of 2007-2009: the role of economic factors in the 50 U.S. states. *Soc. Sci. Med.* 116, 22–31. <https://doi.org/10.1016/j.socscimed.2014.06.015>.
- Preece, D., Hong Ng, T., Tong, H.K., Lewis, R., Carré, M.J., 2021. The effects of chlorination, thickness, and moisture on glove donning efficiency. *Ergonomics* 64 (9), 1205–1216. <https://doi.org/10.1080/00140139.2021.1907452>.
- Public Health Emergency, 2020. Waiver or Modification of Requirements under Section 1135 of the Social Security Act. Retrieved June 7 from. <https://www.phe.gov/emergency/news/healthactions/section1135/Pages/covid19-13March20.aspx>.
- QSR International Pty Ltd, 2015. In: NVivo Qualitative Data Analysis Software (Version 11).
- Rahman, S., Speed, T., Xie, A., Shechter, R., Hanna, M.N., 2020. Perioperative pain management during the COVID-19 pandemic: a telemedicine approach. *Pain Med.* <https://doi.org/10.1093/pm/pnaa336>.
- Ralph, F., Large, D.R., Burnett, G., Lang, A., Morris, A., 2021. U Can't Touch This! Face Touching Behaviour whilst Driving: Implications for Health, Hygiene and Human Factors. *Ergonomics*. <https://doi.org/10.1080/00140139.2021.2004241>.
- Ranoa, D., Holland, R., Alnaji, F.G., Green, K., Wang, L., Brooke, C., Burke, M., Fan, T., Hergenrother, P.J., 2020. Saliva-based molecular testing for SARS-CoV-2 that bypasses RNA extraction. *bioRxiv*.
- Rothrock, L., Abraham, A., Graf, A., Rodopman, M., Nold, D., 2021. Aiding decision makers to reopening of places of worship. *Human Factors Ergon. Manufact. Service Indus.* 31 (4), 349–359. <https://doi.org/10.1002/hfm.20891>.
- Salmon, P.M., Plant, K.L., 2022. Distributed situation awareness: from awareness in individuals and teams to the awareness of technologies, sociotechnical systems, and societies. *Appl. Ergon.* 98 <https://doi.org/10.1016/j.apergo.2021.103599>, 103599-103599.
- Salmon, P.M., Stanton, N.A., Read, G.J., Walker, G.H., Stevens, N.J., Hancock, P.A., 2019. From systems ergonomics to global ergonomics: the world as a socio-ecological-technical system. *Contemporary Ergonomics and Human Factors*. In: *Proceedings of the International Conference on Ergonomics & Human Factors*, first ed. Stratford-Upon-Avon, Warwickshire, UK.

- Salmon, P.M., Stevens, N., McLean, S., Hulme, A., Read, G.J.M., 2021. Human Factors and Ergonomics and the management of existential threats: a work domain analysis of a COVID-19 return from lockdown restrictions system. *Human Factors Ergon. Manufact. Service Indus.* 31 (4), 412–424. <https://doi.org/10.1002/hfm.20897>.
- Sigahi, T.F., Kawasaki, B.C., Bolis, I., Morioka, S.N., 2021. A Systematic Review on the Impacts of Covid-19 on Work: Contributions and a Path Forward from the Perspectives of Ergonomics and Psychodynamics of Work. *Human Factors and Ergonomics in Manufacturing & Service Industries*.
- Spiwak, M., Wooldridge, A.R., Lusebrink, R., 2021. Increasing Diversity and Inclusion in Human Factors. The 65th Human Factors and Ergonomics Society Annual Meeting.
- Stevens, N.J., Tavares, S.G., Salmon, P.M., 2021. The adaptive capacity of public space under COVID-19: exploring urban design interventions through a sociotechnical systems approach. *Human Factors Ergon. Manufact. Service Indus.* 31 (4), 333–348. <https://doi.org/10.1002/hfm.20906>.
- Stiles, S., Golightly, D., Ryan, B., 2021. Impact of COVID-19 on health and safety in the construction sector. *Human Factors Ergon. Manufact. Service Indus.* 31 (4), 425–437. <https://doi.org/10.1002/hfm.20882>.
- Stone, P.B., Nelson, H.M., Fendley, M.E., Ganapathy, S., 2021. Development of a novel hybrid cognitive model validation framework for implementation under COVID-19 restrictions. *Human Factors Ergon. Manufact. Service Indus.* 31 (4), 360–374. <https://doi.org/10.1002/hfm.20904>.
- Sykes, A., Pandit, M., 2021. Experiences, challenges and lessons learnt in medical staff redeployment during response to COVID-19. *BMJ Leader* 5 (2), 98–101. <https://doi.org/10.1136/LEADER-2020-000313>.
- Thatcher, A., Waterson, P., Todd, A., Moray, N., 2018. State of Science: ergonomics and global issues. *Ergonomics* 61 (2), 197–213. <https://doi.org/10.1080/00140139.2017.1398845>.
- Thatcher, A., Nayak, R., Waterson, P., 2020. Human factors and ergonomics systems-based tools for understanding and addressing global problems of the twenty-first century. *Ergonomics* 63 (3), 367–387. <https://doi.org/10.1080/00140139.2019.1646925>.
- Voronina, O., Sopina, A., Volosiuik, A., Ostanina-Olszewska, J., 2021. Attitudes to Teaching and Learning Online in Higher Education during the COVID-19 Pandemic. Congress of the International Ergonomics Association.
- Vosper, H., Hignett, S., Bowie, P., 2018. Twelve tips for embedding human factors and ergonomics principles in healthcare education. *Med. Teach.* 40 (4), 357–363.
- Wilson, J.R., 2014. Fundamentals of systems ergonomics/human factors. *Appl. Ergon.* 45 (1), 5–13.
- Wooldridge, A.R., 2021. The Application of Systems Ergonomics to the Design of a Mobile COVID-19 Laboratory. Congress of the International Ergonomics Association.
- Wooldridge, A.R., Carayon, P., Hundt, A.S., Hoonakker, P.L.T., 2017. SEIPS-based process modeling in primary care. *Appl. Ergon.* 60, 240–254. <https://doi.org/10.1016/j.apergo.2016.11.010>.
- Wooldridge, A.R., 2021. The time is now: developing ergonomics for equity and justice through intersectionality. *Ergon. SA : J. Ergon. Soc. South Afr.* 32 (1), 10–18. <https://doi.org/10.4314/esa.v32i1.3>.
- Wooldridge, A.R., Carayon, P., Hoonakker, P., Hose, B.-Z., Eithun, B., Brazelton, T., Ross, J., Kohler, J.E., Kelly, M.M., Dean, S.M., Rusy, D., Gurses, A.P., 2020. Work system barriers and facilitators in inpatient care transitions of pediatric trauma patients. *Appl. Ergon.* 85, 103059. <https://doi.org/10.1016/j.apergo.2020.103059>.
- Wooldridge, A.R., Carayon, P., Hoonakker, P.L.T., Hose, B.-Z., Schroer, K., Brazelton, T., Eithun, B., Rusy, D., Ross, J., Kohler, J., Kelly, M.M., Dean, S., Rahal, R., Gurses, A. P., 2022. Care transition of trauma patients: processes with articulation work before and after handoff. *Appl. Ergon.* <https://doi.org/10.1016/j.apergo.2021.103606>.
- Xie, A., Saunders, J., Speed, T., Hsu, Y.-J., Khasawneh, A., Kim, S., McDonald, E., Marsteller, J., Gurses, A., Shechter, R., Hanna, M., 2021. Perioperative Pain Management during the COVID-19 Pandemic: A Human Factors Approach to Telemedicine Adoption. Congress of the International Ergonomics Association.
- Zenderski, M., Miranda de Oliveira, P., 2021. The Problems of the Interfaces of the ICU Mechanical Ventilators Evidenced by Covid-19. 21st Congress of the International Ergonomics Association, IEA, 2021.
- Zink, K.J., 2014. Designing sustainable work systems: the need for a systems approach. *Appl. Ergon.* 45 (1), 126–132. <https://doi.org/10.1016/j.apergo.2013.03.023>.