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RESEARCH

Utilising human factors systems approach to support the well-being of healthcare workers: a qualitative study of work system interactions during the COVID-19 pandemic

Siyuan Zhang[1] · **Xiuzhu Gu**[1]

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Abstract
The COVID-19 pandemic has significantly impacted public healthcare systems and healthcare workers (HCWs) worldwide. As direct providers of medical services, the work of HCWs is crucial for the resilience of the healthcare system in response to the pandemic. This study systematically investigates the well-being of frontline HCWs in China and the influence of various work system elements, using the human-centred Systems Engineering Initiative for Patient Safety (SEIPS) model. We conducted semi-structured interviews among 32 HCWs in China, focusing on the six elements of SEIPS: Person, Tasks, Organisation, Tool & Technology, Internal and External Environment. Thematic analysis revealed themes in three categories namely experience, adoption support and future needs. These findings highlight the fact that the interactions between HCWs and work system elements often have greater negative impacts than the health threats posed by the pandemic, emphasising the need for tailored support. This study emphasises the necessity of focusing on the general well-being (i.e., physical, psychological and social well-being) of HCWs, assisting them to manage organisational changes and handle complex work tasks. It also clarifies that the Human Factors Engineering approach used in the study contributes to a holistic understanding of the challenges faced by HCWs and the underlying causes. Consequently, this study contributes to the improvement of future support strategies such as enhancing the effectiveness and relevance, ultimately fostering the general well-being of HCWs to mitigate the global healthcare workforce crisis, and reinforcing the resilience of the healthcare system beyond the pandemic.

Keywords Human factors · Healthcare workers well-being · Work system · Resilience · Qualitative research

1 Introduction

The resilience of a healthcare system refers to the capacity of health actors, institutions and populations to prepare for, recover from and absorb shocks, whether they are public health crises or events that lead to a surge in healthcare service demands (such as disasters or mass casualties), while maintaining core functions and serving the ongoing emergency care needs of the community (Haldane et al. 2021; Kruk et al. 2015). During a public health emergency, it can maintain system stability and adapt to changing circumstances (Haldane et al. 2021). Every healthcare system relies on healthcare workers (HCWs) to meet its objectives; they are an essential core of the healthcare system (Anand and Bärnighausen 2012). Therefore, the well-being of HCWs is crucial as their work directly affects the delivery of medical services (Chemali et al. 2022; Gupta et al. 2021).

Owing to the significant direct impact of psychological issues on job performance and patient safety, numerous studies primarily use quantitative methods to assess the psychological well-being of HCWs (Leung et al. 2024; Sun et al. 2021). However, this has driven most support strategies for HCWs to focus on psychological aspects, making it difficult to address a broader range of factors. The increasing turnover rate reflects the urgency of improving the overall well-being of HCWs. Vividly understanding the experiences

✉ Xiuzhu Gu
xiuzhu.g.aa@m.titech.ac.jp

[1] Department of Industrial Engineering and Economics, School of Engineering, University/Institution: Institute of Science Tokyo, W9-55, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, Japan

of HCWs helps inspire their willingness to improve their well-being efforts, particularly by examining the work-related barriers that HCWs face (Rotenstein et al. 2022). By investigating the condition of HCWs and its impact on system performance, Ray-Sannerud et al. (2015) identified three key dimensions namely physical, psychological and social, which are used to evaluate the overall well-being of HCWs. Physical health issues, such as fatigue and musculoskeletal problems, are common among HCWs; psychological stress is often closely related to the quality of care; and social factors, such as relationships with colleagues and family, affect the resilience of HCWs. Therefore, emphasising general well-being is equally important for improving HCWs' work performance and enhancing the work system.

The COVID-19 pandemic has overwhelmed healthcare systems (Sachs et al. 2022). The pandemic has placed immense pressure on healthcare resources including personnel, medical supplies and infrastructure (Rosenbäck and Svensson 2023). This has exposed the limitations of healthcare systems across various countries, including those in developed nations that were previously considered efficient and resilient (El Bcheraoui et al. 2020). In this context, the physical and mental well-being of HWCs faces severe challenges such as higher infection risks and multiple psychological issues (Ehrlich et al. 2020; Mehta et al. 2021; Nguyen et al. 2020). Furthermore, changes in work schedules and processes have overwhelmed them, affecting the quality of care and threatening the stability of healthcare systems (Biber et al. 2022; Carayon et al. 2021; Koontalay et al. 2021).

Given the central role of HCWs in combating the pandemic, supporting their resilience is crucial for the effective functioning of healthcare systems (Ranzani Rigotti et al. 2022). However, several supportive interventions such as personal psychological counselling that have been implemented at the individual level failed to address organisational empowerment issues (Buselli et al. 2021). Structural resource investment and long-term sustainable support at the organisational level are lacking (Appelbom et al. 2021). The insufficient support strategies reflect a lack of comprehensive recognition of the challenges faced by HCWs and overlooking the influence of the underlying factors and the interconnections. Moreover, there appears to be a mismatch between the risk factors for HCWs' well-being, their needs and preferences and the implemented interventions (Muller et al. 2020). HCWs require evidence-based supportive interventions to help mitigate the impact of the pandemic on their present and future well-being (Kinman et al. 2020).

To date, no studies have either systematically examined the interactions between HCWs and the work systems in which they operate, or the effects of these interactions on their overall well-being (Zhang and Gu 2024). As the healthcare system is a complex adaptive system, the interactions between its components are highly dynamic and difficult to predict (Berg et al. 2018). Previous studies do not consider HCWs' experiences as central elements from a system-wide perspective. Human Factors (HF) is a discipline that focuses on studying and improving interactions between humans and other elements of a system (Aaberg et al. 2021). Systems Engineering (SE), however, specialises in identifying inefficient processes that hinder quality and designing interventions to address these inefficiencies (Padula et al. 2014). Together, these approaches offer a set of methods and principles that facilitate the understanding, modelling, improvement, optimisation and integration of complex socio-technical systems, which typically involve multiple goals and stakeholders to achieve optimal overall system performance (Carayon et al. 2018). Essentially, these methods emphasise the analysis and enhancement of the entire system rather than focusing solely on individual elements to reinforce the interactions among the system's elements (Waterson 2009). Therefore, adopting an HF/SE approach provides valuable insights into the interactions between HCWs and the work system during the pandemic, and then provides a foundation for developing interventions that meet their unique needs and ultimately reinforce the resilience of the healthcare system.

This study aims to apply the HF/SE approach to (i) explore the interactions between HCWs and their work system during the pandemic, (ii) identify the interrelationships between various elements within the work system and (iii) explore potential directions for improving future support based on the individual needs of HCWs. The findings of this study can inform future policy decisions and the well-being support of HCWs in future disasters.

2 Theoretical framework

Complexity theory explores complex systems by focusing on the relationships and interconnections between system components rather than the individual components (Pype et al. 2018). The concept of the Complex Adaptive System (CAS) originates from complexity theory, seeking to take a dynamic approach to both human and non-human agents (McDaniel et al. 2009). Currently, there is no standard method to fully understand complex systems and the environments in which they operate, particularly in terms of identifying complex interrelationships and multiple variables within the system (Berg et al. 2018; Bergström and Dekker 2014). Healthcare is part of a complex sociotechnical system and represents one of the CAS composed of professionals, patients, managers, policymakers and technology, all of which interact with everyday clinical work

and rely on trade-offs and adjustments for success (Berg et al. 2018).

For the complex sociotechnical system of healthcare, Hollnagel et al. (2013) introduced the concept of 'resilient health care' based on resilience engineering. This concept emphasises that healthcare systems and HCWs must possess sufficient intrinsic capacity to continuously adapt, adjust, and improve when faced with complex and unpredictable environments. Compared to Safety-I, which focuses on identifying and addressing contributing factors after human errors occur, Safety-II adopts a proactive approach by identifying potential human-related risks within each element of the work system and mitigating them in advance to ensure smooth operations, thereby maximising the number of expected and acceptable healthcare outcomes (Braithwaite et al. 2015). Furthermore, Safety-II views safety investments as a means of enhancing productivity, aiming to ensure stable operations. Even if no adverse incidents occur following such investments, they still contribute to improving daily performance (Hollnagel et al. 2015). Resilient health care and Safety-II provide a novel framework for understanding the necessity of supporting HCWs in strengthening the resilience of healthcare systems, particularly within distinct social contexts. Improving healthcare resilience proactively not only carries the meaning of improving traditional medical safety but also encompasses the new implications of continuously and stably providing high-quality healthcare services.

Resilience engineering and Human Factors Engineering (HFE) are related fields that consider how people interact with systems and how systems can adapt to change (Gurses et al. 2012). The Systems Engineering Initiative for Patient Safety (SEIPS) model is rooted in the field of HFE (Holden et al. 2013). It describes a systematic approach for evaluating and improving healthcare quality. The overall structure of the model is that the socio-technical work system generates workflows, which in turn yield outcomes. It follows a system-oriented approach where performance results from the interaction of socio-technical systems; it is also human-centred, positioning 'person' at the core of the healthcare work system. This implies that efforts must be made to support individuals by designing work systems that are compatible with their capabilities, limitations, performance needs and other characteristics, rather than contrarily. Additionally, it possesses the capacity for design-driven improvement using practice-based enhancements to promote outcome improvements (Holden and Carayon 2021). Using the SEIPS model's work system component and the resilient healthcare concept, the aims of this study were pursued through an extensive multidimensional analysis of the experiences of HCWs.

3 Research methods

3.1 Research design

This study uses a qualitative design. We collected data through semi-structured interviews using a narrative approach. The data were further analysed using thematic analysis.

3.2 Setting

Narrative encompasses the diverse methodologies that humans use for storytelling about events, blending recounted events with reality (Overcash 2003). It transcends mere event description and becomes an integral part of the events. This approach allows for a nuanced exploration of human experiences and perspectives across various contexts (Carr 1986). This research methodology facilitates the generation of analytical data to address research inquiries (Overcash 2003). Narratives can provide first-person insights into the personal experiences, perceptions, interpersonal interactions and interactions with the environment. Therefore, we applied this approach to examine HCWs' experiences and perceptions during the pandemic. Since 8 January 2023, China has downgraded the control measures for COVID-19 and lifted most restrictions. In the following two months, although small-scale outbreaks occasionally occurred in certain regions, medical institutions generally managed the situation well and gradually returned to regular operations. By April, healthcare services across the country had largely stabilised. Consequently, data collection for this study started from 1 April and cased on 29 December 2023 according to the saturation point.

3.3 Ethical considerations

This study was approved by the university's ethics committee (Reference Number: 2022350). Before the interview, the participants were briefed on the purpose and main content of the study; informed consent and the permission to record the interview were also obtained. Interviews could trigger concerns and memories of negative experiences; therefore, the participants were free to terminate and withdraw from the study at any time. Participants were also informed that they could skip or avoid uncomfortable questions and that the interviews could be interrupted if needed. However, only a few skipped questions; moreover, none of the interviews ended prematurely owing to discomfort. During data collection, participants were anonymised by being assigned ID numbers to ensure confidentiality. Upon the completion of data collection, it was not shared with anyone else. After transcription, the audio files were deleted.

3.4 Participants and data collection

This study included HCWs from various levels of medical institutions within China's tiered healthcare system. The HCWs included physicians, nurses, pharmacists and technicians who had frontline experience during the pandemic. Participants were recruited through convenience and snowball sampling starting in Wuhan. The initial participants were colleagues who met the criteria. To increase geographic diversity, recruitment was later extended through social networking channels following the same criteria. Based on relevant experiences from past studies, no definite deadline was set during the study (Liu et al. 2020). Recruitment of new participants ceased once code and meaning saturation was achieved (Hennink et al. 2017).

Semi-structured, in-depth online interviews were conducted at convenient times for participants. As the peak periods of the pandemic varied across different regions in China, we incorporated opening questions to mitigate potential confusion arising from regional and temporal differences. Participants were asked to recall 'a typical workday routine' and 'the most challenging work experience' during the pandemic (see Appendix 1), enabling them to retrospectively select the most representative period. This approach facilitated more precise recollection of contextual factors and associated experiences. The following interview questions mainly focused on the interactions between participants and various elements within the work system. More specifically, the focus was on how and why these elements influenced the well-being of HCWs during the pandemic, as well as the measures that were implemented to support HCWs' well-being. Additionally, the interviews explored potential unmet needs based on personal experiences.

3.5 Data analysis

Each audio recording was transcribed verbatim within 24 h after the interview and reviewed a second time to ensure accuracy. All transcripts were imported into the qualitative analysis software MAXQDA 2022 Pro for organising and coding text segments. During the coding process, we monitored the emergence of new themes or concepts to determine data saturation. After analysing the first 27 interviews, no substantially new codes emerged, indicating that the data had reached theoretical saturation. Nevertheless, 5 additional interviews were conducted to ensure it. Hence, the final dataset comprises 560 pages of transcribed text for 32 interviews, all of which were included in the subsequent thematic analysis.

Thematic analysis is a method used to analyse qualitative data, involving searching within a dataset to identify, analyse and report recurring patterns (Braun and Clarke 2006). The principles of thematic analysis are embodied in coding data, identifying and refining themes and reporting the research findings (Kiger and Varpio 2020). This inductive coding process ensures that all codes are derived directly from the data, free from pre-existing theoretical assumptions, to identify and review potential themes by transforming the codes and applying the emerging coding scheme to all data, to ensure subsequent consistency across theme levels and verify the relevance of themes to both the codes and the overall dataset. The process was guided by Braun and Clarke's framework (2006), which includes the following steps as illustrated in Fig. 1.

Firstly, we familiarised themselves with the data by re-listening to recordings and carefully reviewing transcripts. All transcripts underwent careful reviews and meaning units relevant to the research topic were assigned open codes. To improve the credibility and confirmability of the data analysis, we employed iterative questioning, code comparison and regular debriefings to determine the final codes (Shenton 2004). Due to the large number of codes, they were grouped into subthemes based on their conceptual similarity. Each subtheme was classified as positive beneficial, negative burdensome, or mixed according to the predominant nature of the codes within it.

We then mapped the subthemes onto the six elements of the SEIPS work system (Person, Tasks, Tools & Technology, Organisation, Internal and External Environment). Related subthemes were grouped together to form

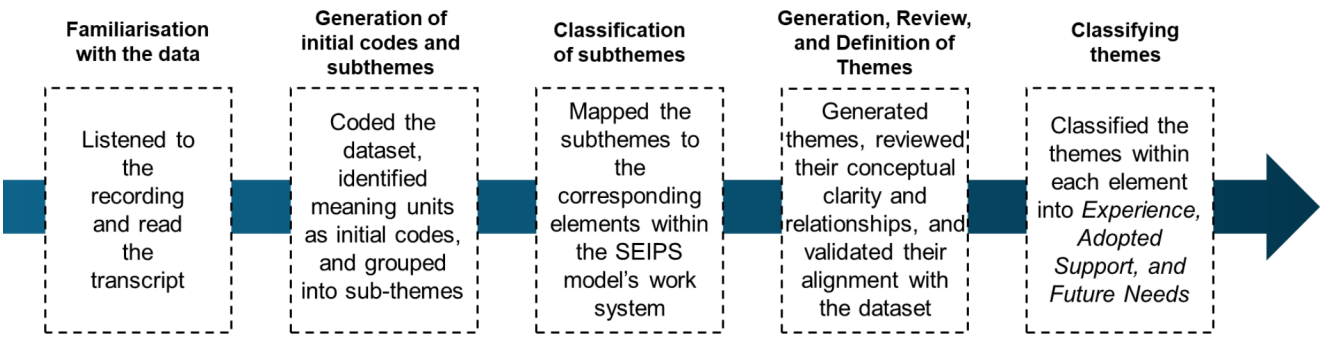


Fig. 1 Data analysis process

provisional themes. This clustering was guided by the conceptual relevance of the fundamental codes rather than any rigidly predefined themes, thereby preserving the inductive nature of the analysis. All themes were examined to verify the summarised concepts faithfully captured the represented data segments. Additionally, each theme was compared against the complete dataset to ensure that no contradictory or supplementary evidence was omitted that might refine its boundaries. We generated names for these themes that could elucidate the essence of each theme and specify the encompassed participants' experiences or perspectives.

To further analyse the relationships among different components of the work system, we examined the co-occurrence of codes within various elements. Specifically, the potential connections between codes were identified through their co-occurrence within the same meaning unit. This co-occurrence indicates that participants perceived a meaningful association between these codes. The analysis firstly identified segments where multiple codes appeared simultaneously within a single statement or closely related sentences. When the co-occurring codes in two different elements contributed to a better work system such as improved work environment and HCWs' well-being, it was classified as a positive connection between the two elements. Similarly, negative relationships and varied relationships depending on case between the six elements were also classified.

Finally, the themes under each element were organised according to three primary categories of information. Experiences encompassed both positive and negative events encountered in work and daily life. Adopted support focused on the support measures that participants had received or utilised. Future needs centred on recommendations and expectations for improving future practices and resource allocation.

Table 1 Characteristics of study participants

Categories	*N* (%)
Gender	
Male	13 (40.6%)
Female	19 (59.4%)
Age	
20–29 years	6 (18.7%)
30–39 years	13 (40.6%)
40–49 years	9 (28.1%)
50–59 years	4 (12.6%)
Profession	
Physician (doctor; D)	9 (28.1%)
Nurse (N)	18 (56.3%)
Pharmacist (P)	2 (6.3%)
Medical technician (T)	3 (9.3%)
Level of medical institution	
Primary hospital	8 (25.0%)
Secondary hospital	4 (12.5%)
Tertiary hospital	20 (62.5%)
Location of medical institution	
Eastern Coastal Region	8 (25.0%)
Central Region	15 (46.9%)
Northeastern Region	5 (15.6%)
Western Region	4 (12.5%)

4 Results

This study included 32 Chinese HCWs. They hold various professions within the healthcare system, primarily physicians and nurses, along with pharmacists and medical technicians. The participants varied in terms of gender, age, and the location and level of medical institutions they were working. Chinese medical institutions follow a three-tier system based on the capacity for healthcare, medical education, and research: tertiary institutions are university-affiliated or large regional medical centres; secondary institutions are medium-sized local hospitals serving multiple communities; primary institutions are clinics providing basic care in communities and rural areas (Chen and Liu 2023). Table 1 provides an overview of the participants and Appendix 2 presents the details.

Our data comprehensively and holistically reflected the participants' experiences and the support they received during the pandemic, and captured their urgent needs, particularly emphasising on the interactions within the work system. Their narratives were categorised into *Experience*, *Adopted support* and *Future needs*. The themes in these three categories were classified based on the SEIPS model into *Person*, *Tasks*, *Organisation*, *Tool & Technology*, *Internal Environment*, *and External Environment*. The details of the themes, subthemes and codes are provided in Appendix 3.

4.1 Person

4.1.1 Experience

4.1.1.1 Theme 1: well-being HCWs experienced severe physical issues during the pandemic and exposure to the virus increased their health risks. Managing the surge in workload and the use of protective gear further added to their physical burden. For the HCWs having underlying diseases, they had to tough it out to fulfil their work during the pandemic.

> *Some of my colleagues have heart palpitations and others have thyroid conditions. I have some breast nodules, but we were too busy to even think about our own health check-ups. (N03)*

Their mental well-being was adversely affected by negative feelings such as fear, anxiety, depression and exhaustion. A typical situation for HCWs was they faced the risk of transmitting the virus to their families, which heightened their anxiety. For example, T27 was conducting sample testing in a hospital where daily reports identified a large number of positive cases. He was highly concerned about bringing the virus home and, as a precaution, repeatedly disinfected himself before arriving home to alleviate his worries.

Their social well-being was affected by the changes of social relations. During the progression of the pandemic, hospitals reallocated HCWs due to workforce shortages. These HCWs had to quickly learn how to treat COVID-19 patients, which posed challenges in adapting to their new roles. For example, D04 mentioned that when assisting in the treatment, she experienced self-doubt when patients asked about their COVID-19 condition. She questioned whether her expertise was sufficient to treat these patients and whether she might inadvertently delay their treatment. During the rapid spread of the pandemic, the inability to assist every patient on time induced feelings of helplessness and lack of confidence, ultimately reducing their sense of social well-being.

> *Our respiratory department experienced a surge in workload. At that time, we had several elderly patients with stable conditions who developed high fevers after contracting COVID-19 virus and ultimately did not survive. Repeatedly witnessing the same outcome deeply shook my belief in my role as a doctor.… I kept thinking that if there had not been such a sharp increase in patients and if we had been under less pressure, they might have held on for a little longer. (D07)*

In contrast, some HCWs experienced a sense of confidence derived from their medical knowledge and profession. This was particularly evident among HCWs in Wuhan, who were the first to confront the pandemic. They summarised their experiences that later helped HCWs in other regions gain a more objective understanding of the pandemic and respond more effectively. They remained committed to supporting the resilience of the healthcare system under immense pressure. As an example, D16 shared his involvement in compiling a guideline based on Wuhan's experiences. His primary contribution focused on strategies to reduce hospital-acquired infections, particularly by implementing hygiene facilities in high-risk areas. He believed that such work contributed to achieving greater social value. Some HCWs relied on their professional skills and sense of responsibility to continue working, thereby earning widespread trust.

> *If friends and family were around the spread of the coronavirus or got infected with it, they would also come to me for related information. I could feel their trust in me, which was also a trust in doctors. This kind of power made me more willing to persevere. (D01)*

4.1.1.2 Theme 2: team cohesiveness During the pandemic, HCWs heavily relied on teamwork to perform tasks. Some team conflicts were exacerbated by the colleagues' inability to manage negative emotions. For instance, N15 was secretly criticised by colleagues for accepting overtime bonuses. Additionally, conflicts arose when colleagues ignored infection prevention protocols or failed to adhere to disinfection measures. However, the shared pressure and challenges led to greater mutual understanding and support, fostering a positive team atmosphere.

> *Some of my colleagues did not follow the hospital's 'one person, one disinfection' rule in the outpatient department, increasing the risk of virus transmission and leading to worries and arguments. (N08)*

4.1.2 Adopted support

4.1.2.1 Theme 1: health support The participants reported that their medical institutions provided basic physical health support. During the peak of the pandemic, hospitals required daily health reports to assess fitness for duty, allowing for necessary rest and preventing severe consequences. Personal health reports reduced risk of fatigue and potential adverse effects. HCWs also received psychological support from family members, friends, professional counselling and management.

> *Local government leaders visited our rest area to check on us. They asked about our work experiences and cared about our lives, making us feel that we were in this together during the pandemic. (D02)*

Medical institutions prioritised the needs of frontline HCWs. Hospitals provided the necessary medication when HCWs were isolated during home isolation and extended this support to their families when needed. These guarantees reassured HCWs and increased their willingness to undertake frontline tasks.

> *The hospital ensured ample medicine reserves to care for HCWs and provided necessary medications to those in need. This gave us sufficient psychological security. (D01)*

4.1.3 Future needs

4.1.3.1 Theme 1: family and personal well-being The participants hoped that medical institutions would prioritise the integrated health of HCWs and not treat them as numbers. While resolving physical fatigue and health issues requires time, institutions should understand the health conditions of HCWs instead of simply assigning jobs. They also emphasised the necessity of long-term psychological support, considering that many psychological issues persist for a long time and short-term psychological therapy is insufficient to help them overcome negative emotions and psychological difficulties.

> *Even though the pandemic is over, I am still seeking ways to improve my negative emotions. It is hard for me to get over the sadness, and I often think about the various experiences at work. (N22)*

Participants expressed concerns about family related stress during the pandemic and desired help. While managing work pressure, HCWs also needed to meet family needs. They wished to reduce family stress. The participants suggested that the local government and residents' associations could help by providing basic care such as purchasing food and supplies for their families to alleviate their concerns about work and life burdens.

> *When I was staying at the hospital working hard, I did not expect society to provide additional benefits for me and my family. I just hoped my family could live normally without worrying about food and medicine shortages. (D16)*

4.2 Tasks

4.2.1 Experience

4.2.1.1 Theme 1: work process The pandemic led to changes in existing work processes. Although several additional procedures were designed to prevent COVID-19 infection, HCWs had to manage more complex workflows. They needed to learn the necessary procedures and integrate the new workflows into their existing work habits. The introduction of new technologies further complicated the original processes. N15 mentioned that digitising medical records added an extra burden to their hospital, as resident physicians were accustomed to reviewing paper records, requiring nurses to record medical information twice.

Moreover, even before the pandemic, doctor-patient conflicts had already become a prominent issue in China and some HCWs needed to make extra effort to maintain strained doctor-patient relationships. During the pandemic, HCWs faced unprecedented challenges in communication such as patients and their families being uncooperative and emphasising individual needs during their work.

> *Patients could not understand the doctors' treatment plans and believed that doctors were not making enough effort. However, it was impossible for doctors to spend too much time on each patient, which led to more potential conflicts. (D07)*

4.2.1.2 Theme 2: Work assignment HCWs faced an ever-increasing workload, requiring them to work long hours and handle unexpected tasks. Many participants indicated that even during rest periods, they remained ready to undertake assignments at any moment. Owing to task allocation or redeployment, they had to adapt to new work environments and some even endured physical and mental stress upon deployment to other cities to provide medical services.

> *During that time (when the number of patients surged), some of our colleagues went to other cities to provide care, leaving us with only half the original staff. I didn't dare turn off my phone even while sleeping because I had to be ready to respond and return to work immediately. (N10)*

HCWs also had to undertake new tasks or additional responsibilities. This meant that they not only had to manage their original medical duties but also undertake new tasks. Nurses were required to perform non-medical duties during the pandemic. For example, N15 had to clean the storeroom and N20's colleagues had to accompany the patients outdoors. They believed that these tasks should have been handled by nurse assistants or specialised personnel, allowing them to focus on nursing and medical care.

> *As the head of the laboratory department, I had to balance existing testing tasks with the newly added Polymerase Chain Reaction (PCR) testing, ensuring that all tests were completed within the required timeframe. With staff numbers continuously decreasing, I had to constantly adjust task allocations for everyone, making it feel like solving a complex puzzle just to keep everything running. (T11)*

4.2.2 Adopted support

4.2.2.1 Theme 1: workflow optimisation Some medical institutions viewed the pandemic as a stress test to identify potential issues in their workflows and advance the digitalisation of the work platform. After the pandemic began, hospitals implemented electronic medical record keeping to reduce close contact and the risk of transmission, thereby improving cumbersome workflows. The optimisation of these processes reduced the workload of HCWs, allowing them to focus more on delivering medical services (N15).

4.2.3 Future needs

4.2.3.1 Theme 1: HCWs-patient Understanding Promoting mutual understanding between HCWs and patients is a prerequisite for the smooth execution of medical tasks. The participants hoped to reduce information asymmetry between patients and HCWs through various means such as prior notification and clear delineation of responsibilities to eliminate patient distrust and establish a good relationship between the two parties. During the pandemic, both patients and HCWs harboured intense negative emotions; therefore, mutual understanding is crucial.

> *The pandemic amplified everyone's negative emotions, making doctor-patient conflicts more likely to arise. I hope for more communication or understanding, as feeling the empathy from patients makes me more willing to respond to their emotional needs. (D12)*

4.3 Organisation

4.3.1 Experience

4.3.1.1 Theme 1: organisational culture The organisational culture of HCWs reflects the practices and beliefs of the institution. Management in some participants' organisations believed that commands were the best way to maintain work efficiency and reduce the impact of negative emotions on work. Consequently, they established a strict culture with a hierarchical structure, where senior staff and leaders held absolute power and cross-level reporting was not allowed. However, participants felt that this hierarchy negatively impacted work motivation and their physical and mental well-being during the pandemic.

> *During the pandemic, our head nurse would give daily speeches, emphasising her authority and demanding constant reports on our work, leaving us with no autonomy. When emergency department nurses asked her minor questions, she perceived it as incompetence on our part and reprimanded us. (N30)*

Medical institutions with a strong safety culture prioritised the well-being of HCWs. By optimising safe working conditions and safety management, they reduced the risk of infection and ensured that HCWs can consistently provide medical services. Hospitals in the relatively developed eastern regions of China showed a higher level of safety culture. For instance, the hospital where N03 was working not only emphasised regular safety education but also encouraged open dialogue between HCWs and leadership teams. Reporting of adverse issues was encouraged and HCWs' psychological burdens were largely alleviated.

4.3.1.2 Theme 2: organisational management Some participants reported that the rigid management of medical institutions worsened during the pandemic, placing significant pressure on frontline HCWs. For example, during the pandemic, some hospitals increased punitive measures to reduce adverse events. HCWs who made mistakes were not only fined but also publicly criticised, placing a heavy psychological burden on frontline workers.

> *He (the department leader) believed that the adverse event must be punished, even though my workload was much higher than usual, he would not consider making any changes. He treated us like machines and cursed us severely. (N25)*

Some hospitals did not provide fair support to HCWs. Tasks such as large-scale community PCR testing were compensated based on workload, whereas those who continued their normal duties in the hospital received no additional compensation. N29 felt frustrated seeing colleagues who prioritised quantity over quality and who received more compensation.

Some HCWs encountered difficulties with treatment plans for infected patients or the use of Personal Protective Equipment (PPE) and medical institutions needed to provide the necessary training and guidance to quickly master this knowledge. However, some participants were assigned to frontline work without training, while others felt that they received rushed training, which was ineffective owing to the lack of more systematic training.

> *The hospital aimed to provide brief training for frontline HCWs, with respiratory department doctors introducing coronavirus and protective measures.*

However, my colleagues and I still felt that it was impossible to systematically acquire this knowledge in such a short time. (N06)

Conversely, some participants indicated that their medical institutions adopted a more relaxed and flexible management approach, which improved the internal atmosphere. Hospitals eased infection control measures when COVID-19 cases decreased, reducing the pressure on HCWs. Other management strategies included leadership listening to frontline workers' opinions and adjusting policies based on feedback such as implementing more lenient disciplinary measures to alleviate psychological burden.

In my hospital, there were no income-related penalties, and adverse events were mainly addressed through verbal education. However, everyone had a strong sense of responsibility, and adverse events were rare as everyone tried their best to avoid problems. (N03)

4.3.2 Adopted support

4.3.2.1 Theme 1: additional allowances Medical institutions and the government provided allowances to frontline HCWs during the pandemic. Some participants were initially unaware of these rewards and were motivated solely by their professional responsibilities. They were pleased with the later subsidies, considering them recognition and a means to achieve their personal goals. Others mentioned that subsidy policies encouraged them to work during the pandemic, thereby alleviating anxiety regarding income.

After we completed the main tasks at the hospital, some colleagues and I would voluntarily support community hospitals because there were additional allowances at that time. (N24)

Considering that many HCWs did not receive adequate rest during the pandemic, hospitals optimised work schedules to ensure that frontline HCWs had minimum amount of rest time and provided paid leave benefits for those temporarily stepping away from frontline duties. As another example, N26 applied for leave due to personal issues. Although the duration exceeded the annual leave entitlement, she was not required to make up after the pandemic.

4.3.2.2 Theme 2: logistical support During the pandemic, medical institutions provided accommodation, meals, commuting and procedural assistance to help HCWs perform their duties more effectively. Some institutions assisted with commuting by arranging transportation for HCWs and securing travel permits for those affected by lockdowns.

Other institutions offered accommodation in hospital dormitories for HCWs who concerned about infecting their families. In addition, N23 mentioned that some of his colleagues stayed in the hospital for a month, with all meals provided by the hospital and delivered to their respective departments to avoid congregating in the canteen.

In the morning, the department manager would ask about our preferences. The hospital canteen prepared lunch for us, and we only needed to wait in the break room for the logistics department to deliver the meals on time. (N32)

4.3.2.3 Theme 3: targeted training Medical institutions conducted targeted training to help HCWs adapt quickly to their working conditions during the pandemic. This training included understanding the coronavirus and treatment plans as well as how to use the necessary tools such as PPE. This training reduced their fear of the unknown and made them more confident in managing complex situations.

Our training covered state-issued COVID-19 treatment guidelines and included care and infection prevention for nurses. All HCWs also needed to enhance their understanding of treatment procedures. (D19)

4.3.3 Future needs

4.3.3.1 Theme 1: humane management The participants hoped that medical institutions would adopt humane management practices to improve the pandemic response of medical teams. Leaders should empathise with HCWs by considering the causes of adverse events and the validity of their demands, rather than rigidly enforcing orders. Additionally, participants sought direct communication channels with management because the current methods failed to convey frontline needs and led to directives that overlooked HCWs' requirements.

When I raised the issue of unfair overtime pay distribution with the head nurse, she rejected me, stating that it was a matter for management to consider. This dampened my enthusiasm for working overtime. (N05)

One of the main demands of HCWs towards medical institutions was the reasonable distribution of work. Participants hoped for more flexible work arrangements, replacing rigid

shift schedules with autonomy to adjust within the team. Owing to the infection risks and personal and family pressures faced by frontline workers, they wished to adjust their work plans autonomously.

> *When I went to support remote areas, I worried about the risks of using public transportation. If I could choose a closer work location, I would feel more at ease. (D04)*

The participants hoped to avoid extra tasks, particularly nurses taking on non-medical duties, during the pandemic. They believed that such tasks should be handled by nurse assistants or dedicated personnel to allow focus on nursing and medical care.

The participants believed that allowances should be based on workload statistics rather than evenly distributed by department staff to avoid demotivating those with heavier workloads. Many institutions lack workload tracking capabilities. Additionally, the participants stressed the need for timely rewards, noting that some institutions failed to fulfil their promises or provide clear timelines, causing uncertainty and doubt among frontline HCWs.

> *Despite receiving strong public support, actual support was very limited. Although the hospital announced the distribution of some anti-pandemic allowances, many did not receive them. This made me very disappointed. (N14)*

4.3.3.2 Theme 2: training and development Frontline HCWs valued training and development opportunities beyond pandemic-specific skills. They sought personal growth but faced unequal access to training. In some hospitals, only HCWs in outward aid programmes received training, whereas those involved in additional tasks felt that they deserved the same opportunities.

> *Assistance project members were often the same colleagues selected initially, as leaders believed their training made them capable. They received more opportunities, while those like me, who stayed in our original positions, missed further study chances. As the situation became better, the hospital ceased offering these opportunities. (N05)*

4.4 Tool & technology

4.4.1 Experience

4.4.1.1 Theme 1: personal protective equipment (PPE) challenges PPE plays a crucial role in protecting the health of HCWs. However, outdated or inappropriate designs lead to usability difficulties, inconvenience and mobility issues, creating challenges in the treatment and care work of HCWs. They use ill-fitting or old equipment and reduce toilet breaks to avoid the hassle of wearing and removing PPE. For example, N17 noted that the current protective clothing generally adopts a one-piece design and is oversized, making it difficult for relatively slender female workers to move and use the restroom.

> *Due to the oversized protective suit, I encountered mobility issues. When a patient called me, I hurriedly moved and stepped on the trouser leg, which caused me to fall. (N20)*

In the early stages of the pandemic, adequate access to PPE was a major issue. Owing to scarcity, HCWs often used lower-grade protection such as surgical masks and face shields, which increased both their risk and concerns. Even when advanced PPE was available, it had to be reused owing to limited supplies. D12 mentioned that he only used full protective equipment during outpatient visits but conserved N95 respirators during ward rounds because it was an internal hospital activity.

4.4.2 Future needs

4.4.2.1 Theme 1: medical resource allocation The needs included equipment and technology. For example, N20 believed that more sizes of protective equipment should be designed according to HCWs different body types, thereby reducing their physical strain at work. N22 suggested that small and medium-sized cities in China need to improve their medical reserve and supply systems, ensuring HCWs have access to sufficient and advanced medical equipment. Additionally, P31 recommended introducing more medica-

tion delivery robots and similar technologies to address the shortage of human resources.

4.5 Internal environment

4.5.1 Experience

4.5.1.1 Theme 1: infection prevention Some participants were satisfied with the hospital's environmental layout and believed that it met the standards for infectious disease prevention, helped reduce the risk of internal infection and allowed them to focus on their work. Some hospitals installed air purifiers to cleanse indoor air and reduce aerosol transmission. Hospitals in Guangzhou implemented strict management and zoning to isolate COVID-19 patients thereby reducing hospital-acquired infections by controlling admission and isolation treatment pathways.

In my hospital, each floor was divided into two separate areas that do not connect, spatially separating the outpatient medical passage from the COVID-19 patient area, which avoids unnecessary movement of personnel. Additionally, the regular daily disinfection routine reassured me. (N28)

4.5.1.2 Theme 2: risk of defects Some participants reported significant deficiencies in their work environments. Neglecting the maintenance of these environments posed a risk of infection. HCWs deployed in other regions encountered poor conditions that did not meet basic infection prevention standards. Moreover, some medical institutions lacked rest areas, forcing staff to rest on-site after continuous work, which did not alleviate physical and mental fatigue.

During community PCR sample collection, due to environmental limitations and a general relaxation of preventive measures, many people did not maintain social distancing. The lack of designated pathways for guidance also led to crowding, inadvertently increasing the risk of infection. (D04)

4.5.2 Adopted support

4.5.2.1 Theme 1: lounge and duty room During the pandemic, medical institutions endeavoured to improve the working environment of HCWs. Some hospitals enhanced the facilities in duty rooms and adjusted the layout to allow physicians and nurses to rest better during night shifts. Other physicians and nurses could use it to rest during the day shift. Hospitals also provided isolation spaces for HCWs. When they were not assigned tasks or discovered infections, they could rest in separate spaces without being disturbed.

When we went to support other regions, we stayed alone in hotel rooms, which not only allowed us to rest well but also prevented us from affecting others. (D18)

4.5.3 Future needs

4.5.3.1 Theme 1: improving working environment Some participants believed that primary care environments should meet minimum public health standards. Many facilities repurposed from other venues failed to meet the infection prevention standards and posed risks to both HCWs and the public. They hoped for optimised facilities and rest areas. While not seeking relaxation spaces, they wanted basic rest areas where HCWs could take breaks.

I think having the opportunity to rest during long continuous work periods is very helpful. As long as I am not resting on the floor, having a simple place to take a short break would be great. (D02)

4.6 External environment

4.6.1 Experience

4.6.1.1 Theme 1: active assistance At the societal level, most of the public cooperated with HCWs believing that their efforts protected everyone's health. The public complied with the requirements and actively supported HCWs. The Chinese government implemented a patient allocation policy to prevent the collapse of the healthcare system. Society prioritised the provision of living resources to medical institutions and businesses focused on the medical supply needs of hospitals.

At the government level, the government also mobilised and organised the public for basic screening work, with community governments organising screenings and providing administrative support beyond PCR testing. The Chinese government unified medical experts and advanced hospital resources, quickly summarising pandemic response measures and developing practical guidelines. These guidelines were distributed among medical institutions to help frontline HCWs manage complex medical demands.

The government brought in external experts to discuss antivirus developments, including coronavirus

sequelae and differentiating between symptomatic and asymptomatic infections. This systematic guidance alleviated everyone's anxiety. (D21)

4.6.1.2 Theme 2: negative obstruction The public's stigmatisation of HCWs severely impacted their motivation and initiatives. In the early stages of the pandemic, the public's fear and stigmatisation of COVID-19 patients extended to them. As the pandemic persisted, prejudice against HCWs increased and public dissatisfaction with real issues often targeted them. The public's misunderstanding and dissatisfaction further burdened frontline HCWs.

Some patients' relatives left the hospital to handle personal affairs and hid their whereabouts upon returning. They deemed it insignificant, but this behaviour increased our management difficulties and raised the risk of coronavirus transmission. (N05)

Despite widespread social support for HCWs, some participants felt excluded because their roles (e.g. pharmacists and medical technicians) were not considered frontline work and therefore did not receive social recognition, which made them feel hurt.

When I saw that the activities were only for physicians and nurses, I felt sad. I am responsible for CT scans and worked throughout the pandemic, even facing many infected patients directly. Why is my contribution considered different from theirs? (T09)

Some participants also stated that the unclear responsibilities of government staff disrupted their work plans. N08 shared that during public PCR testing in initial phase of the pandemic, local community officials were unfamiliar with the procedures driving HCWs to not only perform testing but also handle the registration of those being tested. These additional tasks affected their work schedules.

4.6.2 Adopted support

4.6.2.1 Theme 1: social concerns Social care includes psychological encouragement from media and material assistance. As the pandemic persisted, the public expressed their gratitude through face-to-face interactions or media channels. After the pandemic was contained, some companies offered free transportation and meals, whereas tourist attractions and parks provided free admission. This support effectively alleviated the physical and mental burden of HCWs, enhanced their social well-being and increased their work motivation.

(Previously deployed to Wuhan to provide support) When I was invited back to Wuhan for a visit, I was warmly welcomed by the locals. My heart was filled with immense excitement, and I felt that all the effort was worth it. (D18)

4.6.3 Future needs

4.6.3.1 Theme 1: government role The participants believed that the government, particularly at the primary level, required better coordination and intervention. Reinforcing coordination and resource management at the local government level would reduce the workload of HCWs and simplify their tasks. During the pandemic, the work of HCWs was subject to government allocation; therefore, the government needs to design more detailed management approaches to avoid medical resource waste. D21 suggested that local governments should consider the needs and responsibilities of HCWs when supporting their work, rather than blindly allocating resources to the work site.

4.7 Summary of results

Figure 2 summarises the themes and subthemes of each element within the work system. As explained in subsection of Data analysis, each experience subtheme was classified as positive, negative, or mixed according to the predominant nature of the codes within it. For instance, PPE challenges were negative experiences due to the poor usability and accessibility. In contrast, a strong safety culture and lenient management were classified as positive experiences because they addressed the challenges brought by the pandemic and enhanced the well-being of HCWs. For the mixed experiences, using social well-being as an example, some HCWs reduced their sense of social well-being while others enhanced.

Furthermore, Fig. 2 depicts the complex interactions between different elements. As also explained in subsection of Data analysis, according to the co-occurring codes in different elements, the interactions were classified as positive, negative, or varied relationships depending on case. Figure 2 shows that negative interactions were more prevalent than positive ones. For instance, the negative relationship between the elements of tool & technology and person was identified; one reason is that the lack of PPE increased infection risks for HCWs that reduced physical well-being. The varied relationships depending on case were mainly

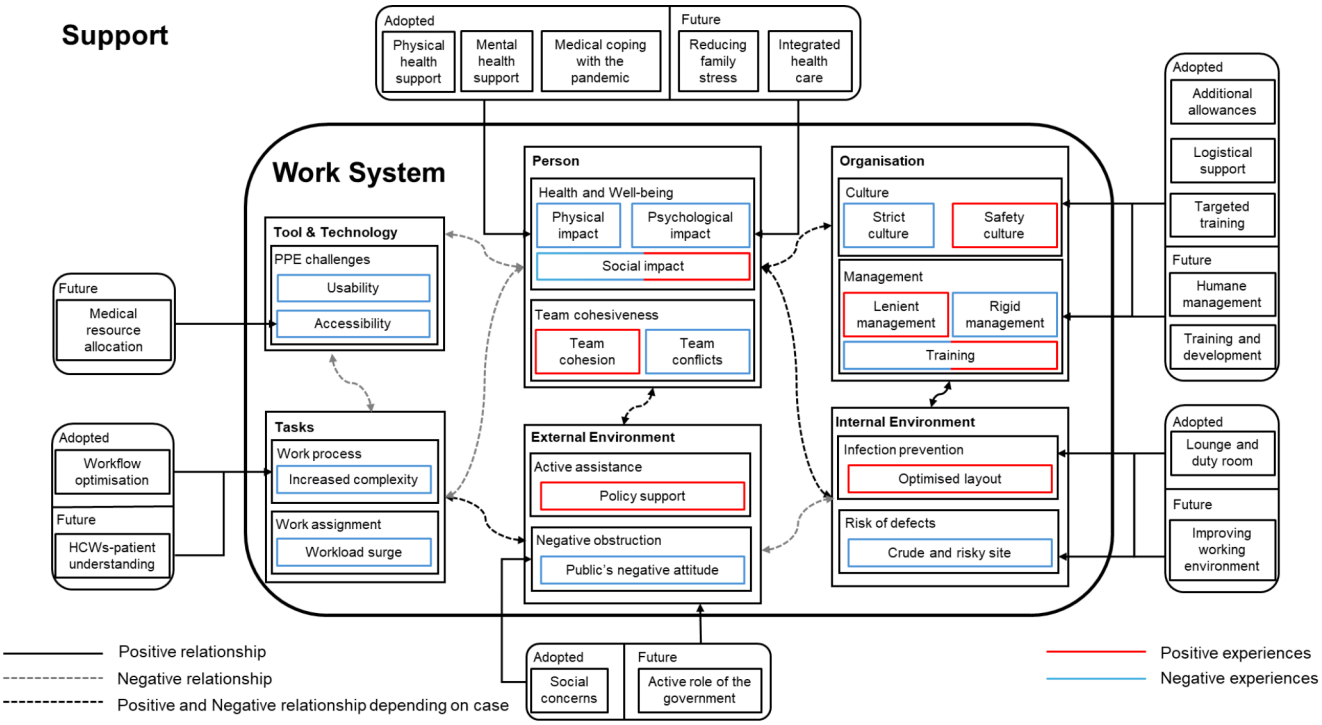


Fig. 2 Themes and relationships in healthcare work system

observed for internal and external environments. For example, policy support measures encouraging reduced travel and non-essential medical visits helped alleviate the surge in workload, but public non-compliance made HCWs' work more challenging.

5 Discussion

This study reveals the challenges and support experienced by frontline HCWs in China during the COVID-19 pandemic and the impact of various elements of the work system on their well-being. The use of the HFE approach helps us to holistically and deeply understand the interactions between HCWs and the work system, thereby effectively improving their well-being, enhance the resilience of the healthcare system and minimise issues related to the misalignment of resources used for support.

5.1 Work system findings

5.1.1 Multifaceted well-being challenges

Most findings of the physical and psychological well-being of HCWs obtained in this study are overlapped with previous studies. HCWs' concerns about their physical health would weaken the medical institution's capability (Shaukat et al. 2020). Design flaws in PPE hindered them from performing their duties (Janson et al. 2022). Excessive fatigue increased the need for rest, highlighting the necessity of improving rest conditions (Dore et al. 2021). The psychological well-being of HCWs was closely related to numerous difficulties in safe work practices, such as insufficient understanding of the virus and life pressures (Hao et al. 2021; Lasalvia et al. 2020). When reflecting retrospectively, HCWs in this study constructed meaning around the experiences, gaining confidence and psychological resilience. However, for some HCWs, negative emotions were magnified over time and this sense of exhaustion may continue to affect their future work. Short-term psychological support was limited in effectiveness as HCWs resisted expressing negative feelings (Huffman et al. 2021; Zara et al. 2021), underscoring the need for long-term psychological support (Solomou et al. 2024).

This study also revealed the importance of HCWs' social well-being that has not been sufficiently investigated. Social well-being among HCWs is often shaped by social norms (Chemali et al. 2022). Social norms are viewed as the public's expectations, attitudes and behaviours towards specific groups (Brown et al. 2019). During the pandemic, the participants experienced unprecedented social recognition and received positive feedback. However, HCWs also felt pressure from 'subjective norms' as they had to continue working on the frontlines to meet societal expectations (Ajzen 1991). Social norm interventions are considered a method to change the behaviour of HCWs (Tang et al. 2021), with

social rewards widely used to enhance the social HCWs' well-being. By increasing the rewards for specific groups, positive effects were achieved, turning passive expectations into a proactive pursuit of work. The participants were provided with additional social benefits and allowances that boosted their motivation to work. Social comparisons also boosted the confidence of HCWs in their work. Numerous studies indicate that in situations where other people's incomes were impacted, the relatively stable income of HCWs became an important reason for them to continue working (Kiwanuka et al. 2024; Morishita et al. 2022; Poon et al. 2022).

5.1.2 Struggling with task complexity

HCWs were overwhelmed by the sudden changes in their tasks and the increased complexity. This result is similar to that observed in other countries (Schaufel et al. 2024). Redeployment, as a key labour strategy during the pandemic, drastically altered the original work conditions of HCWs (Wang et al. 2020). Tan et al. (2020) confirmed that unfamiliar environments lead to greater burnout as HCWs deployed to institutions in urgent need often encountered patients with more severe conditions. Nevertheless, they continued to fulfil their duties under immense pressure, cultivating a stronger sense of responsibility and professional identity (Nilsen and Malterud 2017; Tong et al. 2022).

Considine et al. (2011) found that HCWs feared working in new environments more than during the pandemic. Kennedy et al. (2022) summarised the three major challenges HCWs faced when adapting to new roles and environments including working outside their professional fields, dynamic interpersonal relationships and environmental challenges. Participants relied on their personal beliefs and team support to manage the increased workload and changes in roles and environments. Additionally, improving communication and promoting 'self-selection' could help HCWs prepare beforehand, thereby reducing the sudden pressure when receiving deployment orders (Shabanowitz and Reardon 2009). Empowering frontline HCWs not only provides them with career development opportunities but also enhances their ability to adapt to complex medical environments (Chemali et al. 2022). Establishing comprehensive rapid training systems can help HCWs manage higher care intensity (Brickman et al. 2020). These efforts to help HCWs quickly adapt to new roles will benefit patient care quality and staff well-being (Hettle et al. 2020).

5.1.3 Enduring organisational changes

The finding of this study that organisational culture and management styles have had a lasting impact on the well-being of HCWs during the pandemic is consistent with the previous study (Solomou et al. 2024). Lu et al. (2022) found that healthcare organisations with a safety culture and flexible management styles were more focused on ensuring the safety of both HCWs and patients thereby increasing staff enthusiasm for work and attention to patient care and safety. HCWs are motivated to perform well when they perceive the workplace as supportive and well-managed (Saleem et al. 2021; Sasaki et al. 2020). HCWs believed that humane management was the key to maintaining a positive internal atmosphere and fostering a safety culture as found in this study.

Our study also identified that the supportive leadership provided frontline HCWs with a strong sense of security and confidence in building a safety culture. Vázquez-Calatayud et al. (2022) found that nurse managers as direct supervisors of frontline HCWs played a unique protective role during the pandemic by safeguarding staff at the biopsychosocial level. This is also considered key to addressing inequalities in support. Vogel and Flint (2021) proposed attention, understanding, empathy and assistance elements of compassionate leadership, highlighting the importance of addressing the differentiated needs of HCWs when developing support strategies. The impact of management sometimes exceeds that of the pandemic itself, fully illustrating the need for frontline HCWs to receive appropriate support to maintain their well-being and mitigate the damage caused by the pandemic (Cathro and Blackmon 2021).

5.2 Human factors methodology

5.2.1 Holistic system perspective

Research dominated by psychology and sociology fully reveals the psychological states, emotional responses and mental health of HCWs at the individual level (Leung et al. 2024; Mendoza Bernal et al. 2023; Sun et al. 2021), enhancing public understanding of HCWs' conditions but lacks insight at the system level. However, as a CAS, the diversity and interconnectedness of the healthcare system make it difficult for traditional healthcare improvement models to capture the ripple effects and full scope of various parts of the system (Braithwaite 2018). Systemic factors play an important role in improving the efficiency, safety and resilience of work systems in complex environments (Iflaifel et al. 2020).

HFE follows the 'human-centred' design principle (Rotenstein et al. 2022), placing workers at the centre of the work system, clearly demonstrating the system's operation. Through Human Factors Engineering approaches, the design of effective tools, technologies and processes can help HCWs manage complex tasks and reduce errors (Karsh et al. 2006). In this study, the SEIPS model places HCWs at

the core of the system and explores their interactions with other elements of the work system. This reveals the potential causes of the challenges faced by HCWs and the processes by which these challenges impact them. More importantly, this study addresses their perceptions of support and their demands for managerial support. This approach not only vividly illustrates the experiences of HCWs but also serves as an advocacy tool for management resources and support during crises.

5.2.2 Feedback-driven optimisation

As a dynamic system, the healthcare system undergoes significant changes during special periods such as pandemics (Braithwaite 2018), inducing issues such as delayed support, misallocation of resources and ineffective support for HCWs. Continuous improvement is an effective way to enhance the resilience of a healthcare system in response to changes in internal and external environments (Wiig and O'Hara 2021). The SEIPS model, as a representative model of HFE applied in healthcare, not only describes the current state of the work system but also provides opportunities for future cyclical optimisation (Carayon et al. 2006; Pascale et al. 2022). Existing optimisation strategies have also been evaluated by identifying the causes of negative impacts on HCWs' well-being. Therefore, future optimisation strategies can be based on the current evaluation results and incorporated into work practices, eventually forming a feedback loop. In this study, existing issues in the current support mechanisms such as deficiencies in tools, strict management, and culture were identified. Based on these problems, the proposed strategies will contribute to future improvements and will be continuously evaluated using the same feedback mechanism to achieve system resilience.

5.3 Implications for strengthening resilient healthcare beyond the pandemic

5.3.1 Healthcare workforce challenge

HCWs are the foundation of healthcare systems and emergency response. The pandemic has exposed and exacerbated the long-standing human resource vulnerabilities in global healthcare, including insufficient long-term investment in healthcare personnel, mismatches between labour supply and demand, and poor working conditions, leading to prolonged shortages of HCWs and burnout (Agyeman-Manu et al. 2023). The mental health of HCWs directly affects their job performance, job satisfaction, and retention rates (Alzoubi et al. 2024; de Oliveira et al. 2023). The results of this study not only support this finding but also highlight the impact of physical and social well-being on the work performance of HCWs. Therefore, addressing the pressure of HCW shortages and reducing the long-term work-related failure caused by burnout should focus on enhancing their overall well-being.

Past studies have sought ways to improve the physical and mental health of HCWs by identifying factors related to burnout syndrome. A multidimensional and integrated approach based on various models has, to some extent, identified workplace factors and personal characteristics that contribute to burnout (Nagle et al. 2024). Although this approach can effectively address individual factors, the interrelationships between these isolated factors may remain overlooked. Such problem has been proposed in Li et al. (2024)'s systematic review work that most anti-burnout interventions have focused predominantly on the individual level, with insufficient measures targeting workplace-induced stress and burnout. This imbalance has been associated with a decline in the quality of healthcare delivery. Our study revealed that the challenge in improving the well-being of HCWs does not solely stem from short-term burnout or health issues experienced by individuals; the deeper causes lie in their interrelationships with various elements within the work system. For example, improvements in medical technology can directly reduce the workload outside of clinical duties for HCWs, in turn decrease their physical and mental exhaustion. However, the introduction of technology also requires corresponding training. A systemic perspective that identifies the dynamic interactions between various elements provides important insights into the rational allocation of resources.

Poon et al. (2022) identified individual, interpersonal, work-related, and organisational factors as long-standing contributors to the high turnover rates among HCWs. The findings of the present study reveal the interrelated nature of these factors within the work system. Taking into account the specific needs of HCWs, support efforts may focus on the most salient elements. For instance, enhancing organisational structures and management mechanisms could help optimise workflows and task allocation, thereby reducing team conflict and fostering a culture of safety. This targeted approach offers the potential for comprehensive improvement through strategic investment in key factors.

5.3.2 Proactively enhancing resilience

Resilience is the core of a healthcare system's capacity to adapt and recover. The resilience of a healthcare system is achieved across multiple levels, including workers, teams, units, and organisations (Iflaifel et al. 2020). While supporting the well-being of frontline HCWs to achieve resilience at the workers' level, it needs to focus on creating supportive teams. A good team model will, in turn, guide each HCW

to engage in the work, thereby achieving safer and higher-quality care (Rosen et al. 2018). For medical organisations, it is essential not only to emphasise internal safety culture, management mechanisms, and operational capabilities, but also to pay attention to the impact of the physical environment on HCWs. Designing better healthcare facilities can improve working conditions and staff safety, enabling workers to perform their tasks more effectively (Rechel et al. 2009). Therefore, starting from the well-being of HCWs, enhancing resilience at different levels is key to shaping a sustainable healthcare system.

Safety-II provides guidance for enhancing the resilience of healthcare systems by improving system adaptability to prevent problems from occurring (Provan et al. 2020). The entire healthcare system should focus on proactive investment rather than reactive responses. Like in this study, successful experiences from the various support measures implemented during the pandemic served as effective strategies for resilience and well-being; these successes should be retained and continuously optimised. At the same time, regular assessments of identified shortcomings should be conducted, with ongoing feedback and adjustments to strategies to achieve long-term optimisation.

5.4 Limitations

This study has certain limitations. Firstly, as a retrospective study, the interviews were conducted after the pandemic had largely subsided in China. Although specific questions were designed to trigger participants' memories of key situations, their recollections were inevitably influenced by time and the new environment. These potential recall biases may to some extent affect the accuracy of the experiences. However, from the other perspective, participants' reflections and perceptions may have been reshaped by retrospective appraisal, leading to a more balanced and reassessed perspective rather than an immediate emotional response at the time.

Secondly, this study employed convenience sampling, leading to 47% participants from Central region and lacking representativeness. Although purposive sampling was later adopted to increase the diversity of the samples, it could not eliminate the impact of sample clustering. The uneven distribution of professional groups also made it difficult to make reliable professional comparisons. Therefore, this study limited to identify common challenges among HCWs and systematic factors. Future research would benefit from larger, stratified and more balanced samples to facilitate a deeper understanding of the unique challenges and needs of different groups (e.g., different regions, professions, roles and levels of experience), and then provide more specific recommendations.

6 Conclusion

This study presents an effective work system analysis strategy to support HCWs, aimed at advocating for systematic change and continuous improvement. This study employs an HFE design and the SEIPS model's work system framework to investigate how HCWs had to manage changes in various elements of the work system during the COVID-19 pandemic. These effects extended beyond the health threats posed by the pandemic. The study showed that, along with changes in the work system elements, the general well-being (i.e., physical, psychological and social well-being) of HCWs was affected and these elements directly and mutually influenced each other. The study also highlights existing internal issues in current support strategies such as the lack of fairness and timeliness in support measures. These results underscore the importance of addressing the needs of HCWs and considering the effects of other work system elements. Based on the findings, recommendations are proposed for strengthening the resilience of the healthcare system.

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Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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