frontiers | Research Topics

Emergency, crisis & risk management: Current perspectives on the development of joint risk mitigation, preparedness and response efforts

Edited by
Jarle Løwe Sørensen, Johan Berlin, Laurits Rauer Nielsen and Eric Carlström

Published in
Frontiers in Public Health
Frontiers in Communication
Frontiers in Psychology

ISSN 1664-8714
ISBN 978-2-83251-140-4
DOI 10.3389/978-2-83251-140-4

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Emergency, crisis & risk management: Current perspectives on the development of joint risk mitigation, preparedness and response efforts

Topic editors

Jarle Løwe Sørensen — University of South-Eastern Norway, Norway
Johan Berlin — University West, Sweden
Laurits Rauer Nielsen — University College Copenhagen, Denmark
Eric Carlström — University of Gothenburg, Sweden

Citation

Sørensen, J. L., Berlin, J., Nielsen, L. R., Carlström, E., eds. (2023). *Emergency, crisis & risk management: Current perspectives on the development of joint risk mitigation, preparedness and response efforts*. Lausanne: Frontiers Media SA. doi: 10.3389/978-2-83251-140-4

Table of contents

frontiers | Frontiers in Communication

TYPE Editorial
PUBLISHED 12 December 2022
DOI 10.3389/fcomm.2022.1044231

OPEN ACCESS

EDITED AND REVIEWED BY
J. Brian Houston,
University of Missouri, United States

*CORRESPONDENCE
Jarle Løwe Sørensen
jarle.sorensen@usn.no

SPECIALTY SECTION
This article was submitted to Disaster Communications, a section of the journal Frontiers in Communication

RECEIVED 14 September 2022
ACCEPTED 29 November 2022
PUBLISHED 12 December 2022

CITATION
Sørensen JL, Berlin J, Nielsen LR and Carlström E (2022) Editorial: Emergency, crisis, and risk management: Current perspectives on the development of joint risk mitigation, preparedness and response efforts. *Front. Commun.* 7:1044231. doi: 10.3389/fcomm.2022.1044231

Editorial: Emergency, crisis, and risk management: Current perspectives on the development of joint risk mitigation, preparedness and response efforts

Jarle Løwe Sørensen[1]*, Johan Berlin[2], Laurits Rauer Nielsen[3] and Eric Carlström[1,4]

[1]USN School of Business, University of South-Eastern Norway, Borre, Norway, [2]Division of Social Work and Social Pedagogy, University West, Trollhättan, Sweden, [3]Emergency and Risk Management, University College Copenhagen, Copenhagen, Denmark, [4]Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden

KEYWORDS

emergency, crisis, management, risk, mitigation, collaboration, COVID-19

Editorial on the Research Topic
Emergency, crisis, and risk management: Current perspectives on the development of joint risk mitigation, preparedness and response efforts

In the book Ancient Mesopotamia: Portrait of a Dead Civilization, Oppenheim (1977) describes the old priest-like group, the *Asipus*, who lived in the Tigris-Euphrates Valley. In around 3200 B.C., they were widely known as the first risk analysts. Upon being approached with a problem, they performed probability and consequence mapping, and devised a solution based on their alleged contact with the gods. Although religion and superstition have been closely linked to emergencies and crises throughout history, most modern societies now follow a more analytical, rational, organized and fact-based approach to managing emergencies and crises.

There is an assumption that well-organized crisis management and communication processes reduce vulnerability and help communities cope with hazard-related situations. The problem is that when a crisis occurs, individuals and public and non-governmental organizations tend to prefer standardized and well-known approaches. As a result, they often end up overwhelmed and paralyzed, as they experience difficulties adjusting sufficiently quickly to new situations (Boin and Bynander, 2015). Sources disagree as to exactly why this is, but possible reasons include problems related to vast bureaucracies and decision hierarchies, insufficient knowledge, and failure to prioritize and develop strategic learning aspects of exercises (Berlin and Carlström, 2014). As a result, many stakeholders struggle to meet societal expectations, develop resilient frameworks and find more effective joint solutions.

In this Research Topic, 58 authors have contributed to 12 articles, adding to the development of joint risk mitigation, preparedness and response efforts.

As we are still battling an ongoing COVID-19 pandemic, the focus on a different aspect of public health emergencies has been the most evaluated. As a point of departure, Khorram-Manesh et al. found that armed conflicts are unavoidable with the increasing number of public health emergencies combined with the lack of vital life elements such as water and food. Further, when conducting a knowledge mapping analysis of public health emergency management research for 2007–2020, Yang et al. reported that the research could be divided into three main periods: exploration, growth, and outbreak. By examining the studies chronologically, the study also found that the research has evolved, from examining medical and care aspects related to significant diseases, to focusing more on the management aspect as risk assessment and governance, before currently focusing on the ongoing pandemic.

The COVID-19 pandemic has presented national and international crisis managers with complex and unique challenges. Despite past outbreak experiences, the international community has faced difficulties in joint strategy development and coordination. Governments have been criticized for sub-optimal resource allocation, varying communication strategies and imperfect multiagency collaboration. In their research on healthcare facility resilience between 2000 and 2020, Li et al. found that the research had gone through three main development periods, and that the involved countries and institutions were scattered. Nakahara et al. also addressed healthcare resilience by studying the Japanese healthcare delivery system. Findings showed that, whilst the country's healthcare resources are comparable with other high-income countries, securing beds for patients diagnosed with the coronavirus has taken time. Reasons identified included slow resource allocation, inadequate legal frameworks and a lack of mechanisms for collaboration.

Collaboration is a horizontal and prestige-less effort between stakeholders to solve a common problem (Berlin and Carlström, 2014). However, one of the hallmarks of a crisis is that, compared to everyday emergencies, it requires an immediate response. It quickly strains and overwhelms existing resources. There often arises, therefore, a need to find ways to increase the efficiency of mass dispensing. A common approach in health emergencies is to create points of dispensing (PODs), sites where the government can provide temporary medical services and medications. Alghanmi et al. found that, although effective, there was a need to develop different POD techniques and approaches to meet the demand of groups and populations.

Authorities depend on a compliant public being willing to follow guidance and collaborate, and such willingness requires a basic level of social trust. As pointed out by Reiersen et al., trust can "become a double-edged sword" during a crisis. Drawing on data from 127 countries, the researchers concluded that "the number of COVID-19 deaths decreases with trust in government and trust in science, while the number of COVID-19 deaths increases with social trust" (abstract). The importance of collaboration, more on a national level, was also addressed by Sommer et al.. Their review found that each EU country within the Meuse-Rhine Euroregion addressed the pandemic individually, and that cross-sector collaboration between regional actors was almost non-existent during national policy formulation and decision making.

As COVID-19 has taught us, a global pandemic is not a health problem; it also impacts other parts of our societies and sectors. Therefore, all societies and organizations must mitigate and prepare for a new or similar event, or, to put it another way, they need to build a basic level of resilience. In their contribution, Evenseth et al. explored the promotion of organizational resilience (OR) through the achievement of organizational learning. Their systematic review found that learning was connected to the three OR stages—anticipation, coping and adaptation—and that effective learning depended on appropriate management, systematization and organizational ability. The importance of inner organizational life during the pandemic was also addressed by Sørensen et al., who examined employees' perceptions of organizational crises and their reactions to them in a case study. The results showed a strong belief in the organization's overall resilience level, but a somewhat vague understanding of knowledge, roles and responsibilities resulted in some signs of informal communication and insecurity. Although more challenging in times of crisis than in everyday emergencies, striving to communicate factual knowledge should always be a priority for both authorities and individuals. In today's globalized society, the role and impact of, for example, social media should never be underestimated. As stressed by Chao et al., who in their research article pointed out how the spreading of rumors on social media may have a significant impact on societal order and development, it is of utmost significance for crisis managers to debunk fake information in order to ensure effective crisis management processes.

The differences in and importance of knowledge were also examined by Ochiai et al., who identified significant differences in knowledge and awareness between different working groups, which resulted in, for example, differences in work-willingness and risk-taking. On a darker note, Luo and Qi's analysis of data on 1,825 terrorist organizations recorded in the Global Terrorism Database showed that terrorists were also on a constant quest for knowledge, and were found to study and learn from the experiences of pre-existing terrorist organizations.

The papers published on this Research Topic show the diversity of opinion within the field of crisis management. As the world in which we live becomes increasingly globalized, the need for collaborative thinking and competence-sharing becomes increasingly important, especially when mitigating and responding to events across organizational, national and

international borders. We therefore argue the need for a more unified and collaborative global approach to crisis management.

Author contributions

JS wrote the editorial. JB, LN, and EC contributed with comments to the cited papers and references. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Berlin, J., and Carlström, E. (2014). Collaboration exercises-the lack of collaborative benefits. *Int. J. Disaster Risk Reduct.* 5, 192–205. doi: 10.1007/s13753-014-0s025-2

Boin, A., and Bynander, F. (2015). Explaining success and failure in crisis coordination. *Geogr. Ann. A: Phys. Geogr.* 97, 123–135. doi: 10.1111/geoa.12072

Oppenheim, A. L. (1977). *Ancient Mesopotamia: Portrait of a Dead Civilization*. Chicago, IL: University of Chicago Press.

frontiers in Public Health

SYSTEMATIC REVIEW
published: 28 October 2021
doi: 10.3389/fpubh.2021.765261

Estimating the Number of Civilian Casualties in Modern Armed Conflicts–A Systematic Review

Amir Khorram-Manesh[1,2]*, *Frederick M. Burkle*[3], *Krzysztof Goniewicz*[4] and *Yohan Robinson*[1,2]

[1] Institute of Clinical Sciences, Gothenburg University, Sahlgrenska Academy, Gothenburg, Sweden, [2] Department of Research and Development, Armed Forces Center for Defense Medicine, Gothenburg, Sweden, [3] Harvard Humanitarian Initiative, T.H. Chan School of Public Health, Harvard University, Boston, MA, United States, [4] Department of Aviation Security, Military University of Aviation, Dęblin, Poland

OPEN ACCESS

Edited by:
Laurits Nielsen,
University College
Copenhagen, Denmark

Reviewed by:
Ann M. Sakaguchi,
University of Hawaii at Manoa,
United States
Gamal Eldin Abbas Khalifa,
Egyptian Resuscitation Council
(EgRC), Egypt

***Correspondence:**
Amir Khorram-Manesh
amir.khorram-manesh@surgery.gu.se

Specialty section:
This article was submitted to
Disaster and Emergency Medicine,
a section of the journal
Frontiers in Public Health

Received: 26 August 2021
Accepted: 01 October 2021
Published: 28 October 2021

Citation:
Khorram-Manesh A, Burkle FM,
Goniewicz K and Robinson Y (2021)
Estimating the Number of Civilian
Casualties in Modern Armed
Conflicts–A Systematic Review.
Front. Public Health 9:765261.
doi: 10.3389/fpubh.2021.765261

Objective: To examine the possibility of estimating the number of civilian casualties in modern armed conflicts.

Methods: A systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines, using PubMed, Scopus, and Web of Science search engines. The outcome was analyzed using a qualitative inductive thematic analysis. The scientific evidence of selected article was assessed, using the Health Evidence Quality Assessment Tool.

Findings: The review of 66 included articles in this study indicates that with an increasing number of public health emergencies and the lack of vital elements of life such as water and food, emerging armed conflicts seem to be inevitable. In contrast to military-led cross-border traditional wars, modern armed conflicts affect internally on local communities and take civilian lives. Consequently, the measures and tools used in traditional military-led cross-border wars to adequately tally wounded and dead for many decades under the mandates of the International Humanitarian Law, is insufficient for modern warfare. While casualty counting during modern conflicts is deficient due to organizational, political or strategic reasons, the international organizations responsible for collecting such data (the International Federation of Red Cross and Red Crescent and International Institute of Humanitarian Law) face difficulties to access the conflict scene, resulting in under-reported, unreliable or no-reported data.

Conclusion: There are challenges in estimating and counting the number of civilian casualties in modern warfare. Although the global need for such data is evident, the risks and barriers to obtaining such data should be recognized, and the need for new international involvement in future armed conflicts should be emphasized.

Keywords: armed conflicts, casualties, civilians, estimation, humanitarian law, tool

INTRODUCTION

The last decades' increase in globalization has contributed to an interdependency of the world's economies, cultures, technology, and populations through increased cross-border connectedness, exchange of information, trade, and mutual use of technique and routines (1, 2). This interdependency has further minimized perception of hostilities from other states, enhanced diplomatic agreements, military or economic alliances, resulting in an increased unwillingness of states to use military force unilaterally against another state and consequently a decline in the number of military-led cross-border traditional wars, hereinafter called Traditional Wars (3, 4).

While some may perceive globalization as an advancement for human society, which despite a need for continuous adjustment, promises new opportunities for all, others perceive globalization as a vehicle of economic and cultural disaster, and the main cause of the decline in the value of existing territorial interstate border, cultural and national identity (2, 5). The loss of identity and sense of belonging to a mutual goal results in the global rise of nationalism, and other types of reactionary movements, such as religious, and political, increased polarization in the society, and fosters extreme views and actions, leading to terrorism and modern armed conflicts (5–11).

Both traditional wars and modern armed conflicts have crucial impacts on society and result in material destruction and human losses. One way to evaluate the destructive outcomes of a war or an armed conflict is to estimate its impacts on human life (12–18). Knowing the utilized military means and strategies and their anatomical and physiological impacts on the human body along with registered data regarding the number and type of injuries from previous wars, the outcomes of a traditional war, in terms of mortality, morbidity, and the number of casualties has long been predictable, recorded, and debated (14–17). The information provides a reasonable ground for mental and practical preparedness before a war. This readiness has enabled estimation of needed resources for immediate assessment, treatment, and transport of victims, and has resulted in the development of military medicine, pre-hospital care, and mass casualty (injured and or killed) management (12, 13).

In contrast to traditional wars, modern armed conflicts involve networks of state and non-state actors with various means of military and militia influences and strategies. Such a combination creates difficulties in predicting the means and strategies associated with an armed conflict (9, 10, 12, 19). In addition, warfare in the 21st century constitutes multi-domain operations, asymmetry, and a hybrid approach (19–25). In hybrid warfare, the target of warfighting is not limited to the military staff and includes even civilians by creating political instability, conventional assaulting methods, riots, disinformation, influencing social media, and electoral outcomes (19, 21). Consequently, hybrid warfare may result in a larger number of civilian casualties not included in earlier estimation tools for traditional wars. The inability to estimate the casualty rate (16, 17) influences the calculation of needed resources, which creates a troublesome situation for the affected state and international help organizations. Particularly, the national healthcare contingencies organizations are dependent on predictions of medical support and resources needed to treat casualties (9, 10, 13, 26). Currently, casualty calculation relies mainly on registered and recorded data from earlier conflicts. While such data exist for traditional wars (14), it is missing in modern conflicts, reflecting the conflicting information regarding deaths and injuries from unreliable sources and conflicting estimations methods in modern conflicts (15–18).

With an increasing number of public health emergencies and the lack of vital elements of life such as water and food, emerging armed conflicts seem to be inevitable (26). This review aims to highlight the differences between traditional wars and modern conflicts, examine existing casualty estimation tools and evaluate the possibility of foreseeing the medical impacts of 21st-century warfare on the civilian population concerning the number of casualties, mortality, and morbidity.

METHODS

Study Design, Searching Engines, and Searching Keywords

This systematic review was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (27). According to PRISMA, the searching process yields an accumulated number of articles in the first step. In the next step, duplicates and non-relevant articles are removed. The abstracts of the remaining studies are studied to assure eligibility and relevance. A qualitative thematic analysis of the included literature based on an inductive approach is applied. This content analysis aims to study all included articles, focusing on similarities and differences in the findings to present the tentative results (28). Finally, each eligible article is thoroughly reviewed and the data, including the year of publication, author's name(s), the title of the study, and its scope are registered. The scientific evidence of each selected article is assessed, using the Health Evidence Quality Assessment Tool (**Appendix 1**), as Strong, Medium, or Weak (29). The initially designed electronic search model used PubMed, Scopus, and Web of Science to create a list of available literature in English, using the following search string: Armed conflict; Casualty estimation; Hybrid warfare; Mass casualties; Morbidity; Mortality; Traditional war; alone or in combination. The search was limited to literature in English and Russian language. The Swedish Defense University provided the latter.

Inclusion and Exclusion Criteria

Inclusions criteria: Original publications and reviews dated January 2000 to July 2021.

Exclusions criteria: Proceedings, editorials, news, abstracts, and non-relevant papers.

Ethical Approval

This study complied with the ethical principles stipulated by Swedish law. In Sweden, ethical approval is mandatory if the research includes sensitive data on the participants such as race, ethnic heritage, political views, religion, sexual habits, and health or physical interventions, or uses a method that aims to affect the

person physically or psychologically. This study did not involve any human material or data regarding individuals and was based on available published data in scientific sources.

RESULTS

Initially, using "Armed Conflict" as the keyword, 136,476 publications were identified through the search engines. The number of hits was reduced to 2,501 by adding "Casualty Estimation," and to 152, when all keywords were included. All included studies were reviewed. Special attention was paid to references within each eligible study that did not exist in the primary list to cover missed papers. The final list of publications was studied thoroughly and later included in the review (**Figure 1**). Summary of each paper, along with article information was transferred to a Microsoft Excel File and are presented in **Appendix 2**. Qualitative assessment of the included articles and content analysis allowed distinct categorization of the outcomes in diverse subgroups (see below). Articles categorized in each section were reviewed and relevant data were extracted.

The Change of Paradigm in Warfare

There has been a change in warfare from military-led cross-border traditional wars (Traditional Wars), to those focused on local communities, and civilians (12, 19, 30). During Napoleon's wars, as well as other traditional wars, soldiers were the primary target and constituted the main group of casualties. Local civilians were warned, allowing them to flee their homes and hide to protect themselves from deaths and injuries (12). However, with advances in the arms industry, and changes in warfare strategies and ideologies over the last decades, the battlefields have moved into civilian's backyards, making them more vulnerable to and involved in wars (9). Consequently, there has been an increase in civilian fatalities from 5% at the turn of the 19th century to 15% during World War I (WW I), 65% by the end of World War II (WW II), and to more than 90% in the wars during 1990's, affecting more children than soldiers (12). During this period, there has also been a continuous blunder for the International Humanitarian Law (IHL) and Geneva Convention (GC) in favor of tactical and strategical harvesting, religious and political hatreds, the collapse of State structures, mastering the scarcity of natural resources, the vast availability of weapons, increased acts of terrorism and the spread of asymmetric conflicts (12, 31). **Table 1** presents the available minimum reported number of totals, military, and civilian deaths in some major wars and armed conflicts (1950–2019), demonstrating the changing paradigm of warfare from the traditional wars to locally-focused armed conflicts (32–35). The civilian death ratio obtained by dividing civilian deaths by the total number of deaths aims to compare the outcome of the various war and to indicate a possible trend.

Besides the paradigm change, the available data demonstrates a variation in the rate of civilian deaths. Shorter and probably more intensive wars seem to be associated with a higher number of civilian deaths, while recent long-term conflicts show a lower rate of civilian deaths, a decline in the number of military deaths, as well as, a decrease in the number of foreign military service members participating in different conflicts. The latter might be indicative of an increasing number of proxy wars (16, 17).

The Reliability of Data Regarding Deaths and Injuries

Reporting the correct number of deaths and casualties is required for the selection of necessary measures to avoid human catastrophe. In agreement with other published data, **Tables 1**, **2** show the varying estimate for death tolls presented in this review (36, 37). Although some variations, the casualty reports concerning terror attacks, presented in **Table 2**, seem to be more reliable than the one from modern armed conflicts (**Table 2**). These differences may indicate the diversified information obtained in each conflict due to differences in analyzing methods, or other reasons such as:

First, the traditional wars symbolize an armed disagreement between two or several countries, normally following the International Humanitarian Law (IHL) (12, 38). IHL is a set of rules, which seek humanitarian reasons, to limit the suffering, losses, and other effects of armed conflict by restricting the means and methods of warfare to protect individuals who are not or are no longer participating in the hostilities (30). According to IHL, "A State" has the responsibility for all attributable violations of IHL committed by its organs (including its armed forces), and persons or entities it empowered to exercise elements of governmental authority. It is also responsible for the deeds of those acting in fact on its instructions, or under its direction or control, and by private persons or groups, which it acknowledges and adopts as its conduct (30, 38, 39). In contrast to traditional wars, there is constant negligence of IHL and GC implementation in modern armed conflict. It is simply much more important to achieve the tactical and strategical goal in a conflict than saving civilian lives (12, 30).

Moreover, three international bodies are mainly involved in the development and implementation of IHL. The International Federation of Red Cross and Red Crescent Movement (IFRC), and the International Institute of Humanitarian Law (IIHL). The former is one of the three components of the International Movement, which besides IFRC, also consists of the International Committee of the Red Cross (ICRC), and Red Cross Red Crescent National Societies. ICRC is an operational institution that protects victims of conflicts within a country as well as across boundaries, while IFRC is the largest humanitarian organization. The IFRC coordinates between National Red Cross and Red Crescent Societies globally and along with ICRC supports the foundation of new National Societies in countries where no official society exists. A National Society becomes a member to the IFRC only after the ICRC recognizes it. These organizations work in close collaboration with other international organizations dedicated to the humanitarian cause, such as the United Nations High Commissioner for Refugees (UNHCR), and have operational relations with the European Union (EU), North Atlantic Treaty Organization (NATO), and others (38–40). According to IHL, ICRC have the mandates to gain insights into an ongoing conflict, and as an impartial, neutral, and independent organization protect

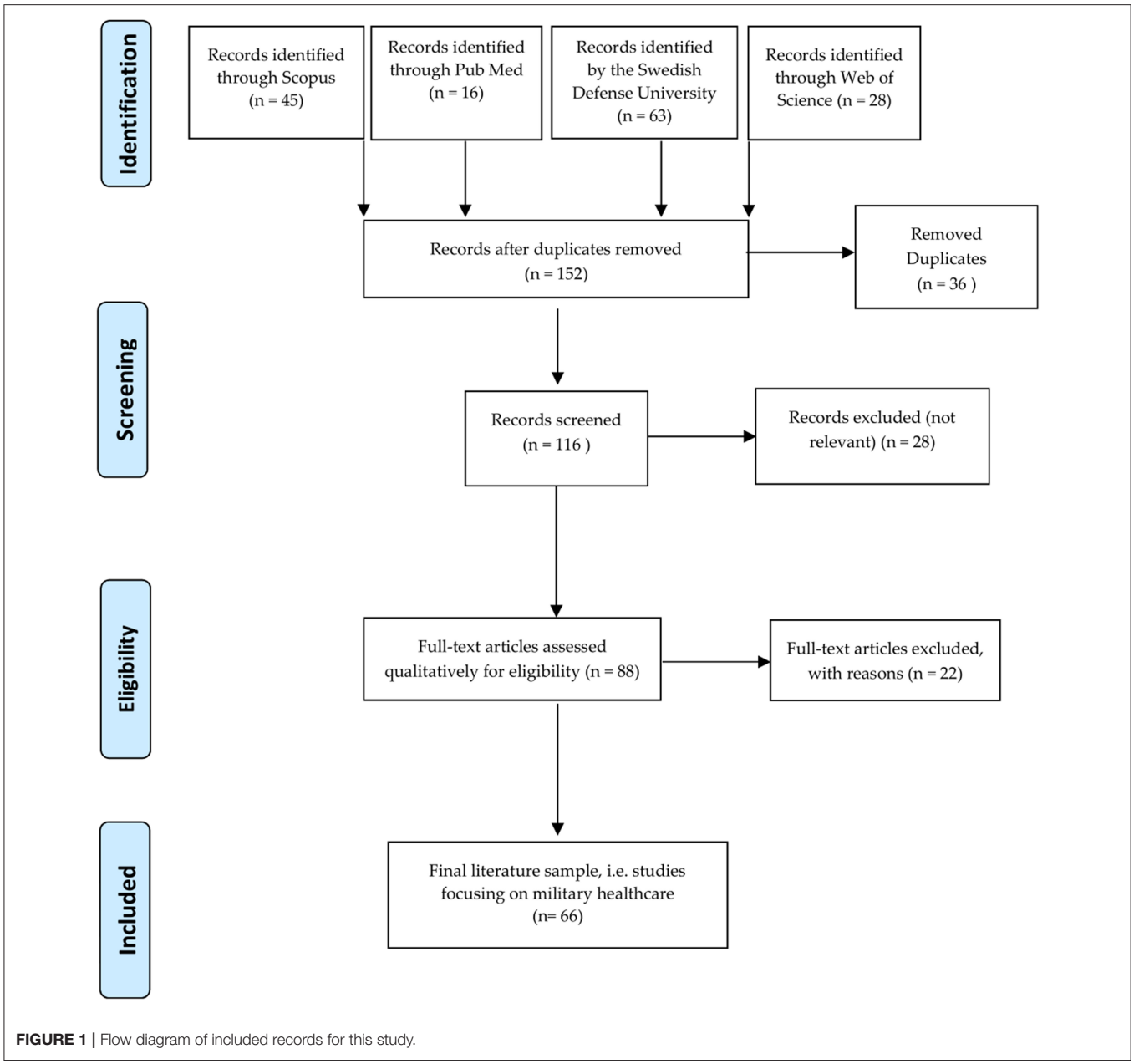


FIGURE 1 | Flow diagram of included records for this study.

the lives and dignity of victims of war and internal violence. They assist the affected population, direct and coordinate the international relief activities, promote the importance of IHL, and draws attention to universal humanitarian principles (40, 41). Additionally, they also have mandates to visit prisons, organize relief operations, reunite separated families, meet the needs of internally displaced persons, raise public awareness of the dangers of mines and explosive remnants of war, and trace people who have gone missing during conflicts (40). All these tasks give ICRC a possibility to track war activities and to present a real picture of the war in terms of the numbers of casualties and deaths. In contrast to traditional wars, modern armed conflicts involve networks of state and non-state actors with various means of military and militia influences and strategies. Such a combination creates difficulties in the implementation, control, and evaluation of IHL's "A State" responsibility principle and does not allow international organizations to get an insight into an armed conflict (9, 10, 12, 30).

Furthermore, casualty recording is a systematic and continuous process of documenting individual direct deaths from armed conflict or widespread violence (42), which is normally conducted by public services normally involved in recording deaths, such as hospitals, coroners, and police forces, within determined scope, usually bound by time and location. While the internal structure of states can be intact

TABLE 1 | The outcome of wars/conflicts in terms of mortality.

Major Military Conflicts						
Conflict	**Period**	**Total deaths**	**Military deaths**	**Main foreign army**	**Civilian deaths**	**Civilian death rate**
Korean War	1950–1953	2,238,172	579,736	33,686	1,658,436	74%
Vietnam War	1965–1974	1,353,000	726,000	58,200	627,000	46%
Persian Gulf War	1990–1991	162,341–232,541	20,341–26,541	341	142,000–206,000	87%–88%
Balkan War	1991–2001	130,000–140,000	-	-	72,716	52%–56%
2nd intifada	2000–2007	5,848	2000	-	3000	51%
Afghanistan	2001–2019	157,052	113,481	2,298	43,571	28%
Pakistan	2001–2019	66,063	41,956	0	24,107	36%
Iraq	2003–2019	276,363–308,212	91,626–100,701	4,572	184,737–207,511	66%–67%
Syria/ISIS	2014–2019	179,424	129,572	7	49,852	28%
Yemen	2002–2019	90,072	78,003	1	12,069	13%
Ukrainian	2014–2019	13,117–13,496	9,750–10,129	500	3,367	25–26%

Conflicts with unreliable or missing civilian death numbers are not included, e.g., Yom Kippur, Chechnya, and Iran-Iraq war. (- = Not available).

TABLE 2 | The outcome of some major terror attacks in terms of mortality and morbidity.

Major Terror Attacks					
Attack	**Year**	**Number of deaths**	**Number of injured**	**Ratio deaths/Total casualty**	**Means of terror**
Oklahoma City	1995	167	759	18%	Explosion
New York	2001	2,996	6,000	49%	Explosion
Madrid	2004	191	2,000	9%	Explosions
London	2005	56	775	7%	Explosions
Boston	2013	3	281	1%	Explosions
Paris	2015	129	300	30%	Explosions
Brussels	2016	35	300	10%	Suicide Bombing
Las Vegas	2017	58	600	8%	Gunshot
Sri Lanka	2019	279	593	32%	Suicide Bombing
Christchurch	2019	51	49	51%	Gunshot

in a majority of traditional wars (may not apply to invaded nations), these entities are no longer functioning effectively in many armed conflicts. In contrast to traditional wars, modern armed conflicts target the local structures, organizations, and public services and aim at destabilizing the authorities and societal networks (13, 30, 31, 41, 43–45). Warfare in the 21st century constitutes multi-domain operations, asymmetry, and a hybrid approach (19–22). In hybrid warfare, the target of warfighting is not limited to the military staff and includes even civilians and the social structure of a nation by creating political instability, conventional assaulting methods, riots, disinformation, influencing social media, and electoral outcomes. Consequently, hybrid warfare leads to a society in chaos with no functional entities. In such a society, the ordinary sources of reporting do not exist and the reliability of information and information sources are questionable. Thus, influencing the calculation of needed resources and creating a troublesome situation for the affected state and international help organizations. Particularly, the healthcare system, which fails to predict the medical support and resources needed to treat casualties (9, 10, 23–25, 30).

Finally, there might be political reasons why state authorities do not publish or share information on conflict-related deaths or might create a different definition for a civilian casualty. Several nations in conflicts are governed by autocratic regimes, which have failed to adopt investments in public health infrastructure, education, and prevention measures to keep pace with population growth and density (41, 46). These nations have leaders that do not understand the impact and consequences of war and armed conflicts, as well as, other disasters and emergencies on their population. They directly influence health security, and structure and create situations with adverse political and economic outcomes that only complicate the crisis further (41). Consequently, in the absence of official recording processes, casualty recording is frequently conducted by civil society organizations, or some internationally mandated entities, such as United Nations peacekeeping missions (42, 47, 48). While these organizations might be widely present in traditional wars, their

presence in modern armed conflicts is limited or non-existing, resulting in conflicted and unreliable reports from other sources.

CURRENT CASUALTY AND DEATHS STATISTIC

Interstate Wars

Compared to WW II (**Table 1**), the number of civilian deaths and injuries caused by rockets and bombs decreased in Korean War, while the mortality caused by grenades, land mines, and other fragmentary explosions increased in both civilian and military populations (34, 35, 49, 50). Consequently, the civilian death rate in Vietnam decreased to 46% compared to that of 74% in the Korean War (51). The former lasted 3 years, and the latter is around 10 years. During the first Persian Gulf War, the civilian death rate increased to 87–88% with a variation in the number of civilian deaths and an undefined number of injuries (43, 52, 53). The multiple ethnical wars in Former Yugoslavia (1991–2001), on the other hand, lasted almost 10 years and resulted in lower civilian death rates of 52–56% (54–56). Estimates of civilian casualties from the Israeli–Palestinian conflict differs both in numbers and sources, however, the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) reported a civilian death rate of 51% from the beginning of the second intifada in September 2000 until the end of July 2007 (47).

The still ongoing conflicts in Afghanistan, Syria, Pakistan, Iraq, and Yemen represent armed conflicts, which engage several countries, militant groups, and strategies. There are contradictory reports of civilian death rates from these conflicts ranging from 28% in Afghanistan, 36% in Pakistan, 67% in Iraq, 28% in Syria, and 13% in Yemen (34, 57–59). Although the civilian casualty ratio for drone strikes is notoriously difficult to quantify, the U.S. estimates a very low number of civilians killed from its drone strikes in Pakistan. A recent study found non-militant casualty rates starting high but declining steeply over time, from about 60% (3 out of 5) in 2004–2007 to $< 2\%$ (1 out of 50) in 2012. The study puts the overall non-militant casualty rate since 2004 at 15–16% (59).

A few reports are available from Russian's involvement in foreign missions. The estimated number of deaths and injuries during Russian foreign missions are around 17,453 deaths and 471,406 injuries from 1946 to 1989. The total numbers reported for 1901–1999, including world wars are 12,132,668 deaths and 35,669,180 injuries. Only during 1939–1945, were 3,392 deaths and 8,738 injuries per day reported. Although high, the reported figures for WWI (1914–1918), and the Russian civil war (1918–1922) are slightly lower. It is not clear how many of these were military service members and how many civilians (60, 61). The Chechen Wars resulted in a large number of civilian deaths. According to Russian sources, the number of deaths and injuries in the first Chechen war was 3,927, and 17,892, respectively. The number of injured in the second Chechen war is missing but 3,669 were dead. There is no information about civilian deaths and injuries (61–63).

The recent Ukrainian armed conflict, which started in March 2014, and in the aftermath of the 2014 Ukrainian revolution, has engaged Russia-backed anti-government separatist groups and Ukrainian Army, National Guard, and voluntary organizations. The conflict has all ingredients of a proxy and hybrid war, in which different parts claim superiority over the others with high impacts on civilian life. The United Nations (UN) reports over 13,000 deaths from April 2014 to February 2020. The number of civilian's deaths reported is 3,367 from April 2014 to July 2020 (civilian death rate = 26%). The reported number of military and voluntary forces deaths are conflicting (64–67).

Finally, the recent Nagorno-Karabakh conflict between ethnic Armenian and Azerbaijani armies has resulted in many casualties and deaths with both sides downplaying the number of their casualties and exaggerating the numbers of enemy casualties and injuries (68).

Terror and Internal Conflicts–a Part of Future Hybrid Warfare

The data demonstrated in **Table 2** concerning some recent terror attacks, indicates the new wave of internal conflicts and terror. The target of these attacks is the local communities and civilians. The intensity and severity of attacks are diverse and the number of deaths and injured diversified. The majority of cases represent political and religious motives. Explosives and suicide bombings have been the main means of terror. Almost all injured and deaths are civilians, with a variation of death numbers from 3 to as much as 2,996, and injured from 49 to 6,000, and a ratio of deaths/total casualty of 8 to 51% (69–77). One important denominator of these attacks is the chaos and overwhelming pressure they created for emergency services, particularly healthcare. The number of deaths is not an immediate concern, however, a high number of injuries require both a multiagency approach and availability of healthcare in several hospitals and healthcare facilities, along with a local preparedness at the community level for both adult and pediatric conditions and military-like injuries.

Calculating Civilian Casualty in Modern Armed Conflicts

In this review, the rate of civilian mortality varies from 13 to 87%. Previous studies have reported a civilian casualty rate of 65 to 70% of the total casualties in a war (13, 32–35, 49). The number of deaths and injuries in the future modern armed conflicts can only be assessed hypothetically since each conflict has its characteristics. However, as shown in this study, the number of civilian casualties will still be high and might be comparable with that of wars in the former Yugoslavia, and Syrian (54–56). The figures from the domestic conflicts do not influence the total number of civilian casualties and deaths markedly. However, its significance lies in the fact that multi-level confrontations and assaults result in resource scarcity, particularly within the healthcare systems, over a longer period, causing a rise in the number of deaths, and a need for serious medical decision-making (5, 9, 13, 44, 78–82).

Assuming that the number of deaths is a technical problem, the overwhelming number of injuries will be the cause of the collapse in all systems (11, 19, 83). The 90% increase in the global urban population in developing countries over the next

two decades increases these nations' vulnerability to political and social unrest, violent crimes, terrorism, disasters, and armed conflicts (81, 84). However, previous estimation algorithms, such as the one introduced by Kuhn used for traditional wars (14), fail to estimate the casualty and mortality numbers of future armed conflicts.

DISCUSSION

The aims of this review were to highlight the differences between traditional wars and modern conflicts, investigate existing casualty estimation tools and evaluate the possibility of foreseeing the medical impacts of 21st-century warfare on the civilian population concerning the number of casualties, mortality, and morbidity. Although this study fails to find a simple algorithm to estimate civilian casualties, it outlines a change in warfare paradigm from traditional wars to modern, locally-focused conflicts (11, 18, 19). Furthermore, it recognizes the involvement of a larger portion of civilians in modern conflicts and consequently a large number of casualties that the ordinary healthcare system may not be able to manage, with or without a reliable and modern casualty estimation tool (15–17). Finally, it also highlights the continuous negligence of the International Humanitarian Law and Geneva Conventions in the recent conflicts, which not only prevent the mandated international organization to surveil the modern conflicts but also threatens the democracy and well-being of a world exposed to continuous change and emerging hazards (12, 26, 41).

Although, efficient and appropriate estimation of the number of deaths and wounded is a necessary part of mass casualty management, it remains challenging in both civilian and military settings due to several decisive factors (12, 15–17, 34, 35, 49, 57, 84, 85):

a) The maximum capacity of each system: There is always a limit on how expandable a system is due to financing and available resources?
b) The shape and condition of the infrastructure: There is always a limit on how many facilities can be used and if the transport routes to these facilities are intact?
c) The grade of preparedness (resilience and resources): Are all entities, including communities, prepared, and is the collaborative element of preparedness exercised and trained?
d) The etiology and cause of mass casualty including the weaponry used: Chemical, Biological, Radiological, Nuclear, or Explosives. Terrorism or interstate invasion?
e) The incident's (combat) size and intensity: Large or small area, long- or short-term?
f) The demography and density of the population involved. Populations background concerning aggressors. High- or low-populated areas?

The slow transition of traditional wars with mainly military engagement to very different modern conflicts, engaging civilians has not only brought about a change in warfare paradigm but also an increase in the number of civilian casualties (11, 12, 19, 34, 35, 49, 78–80, 85). The current state of globalization and the technological advancement within the arms industry enable nations to avoid interstate conflict and direct involvement, using proxy fighters and escaping state's responsibility in following the International Humanitarian Law and Geneva Convention (24, 25, 30, 85, 86).

The collection of data under the IHL mandates by ICRC, among others, facilitated the necessary information to limit and guide the use of weaponry and to protect civilians, and assist both sides of the war. While the use of the casualty estimation tools in traditional wars enabled the tally and management of the casualties, it did not include the count of civilians since the rules of wars were different (12, 30, 40, 44). The use of new technology and the development in the weapon industry and safety items such as body armor has resulted in a decline in the number of casualties caused by direct fire and small arms injuries. Furthermore, the development of trauma care and evacuation option has also resulted in fewer injuries and deaths on the military side (34, 35, 79–81, 87–91). Nevertheless, these successes have also resulted in the development of isolated, local, and urban conflicts, high rates of explosions, and close encounters, influencing the civilian population.

New military strategies, remote warfare, and the use of drones, proxy fighters, and hybrid warfare, present the face of modern and unconventional warfare, which not only threatens and takes civilian lives, but also raises new ethical and moral concerns when violating IHL and GC (12, 30, 81, 82). Additionally, modern conflicts generate millions of displaced persons, which overwhelms the capacity of healthcare and involved relief organizations (26, 64–66, 80–95). Such development increases the vulnerability of protective authorities, consumes legal and healthcare systems, paralyzes the national government and finally may dissolve national unity (9, 25, 30, 45). These are all factors that enhance the violation of human right and equality with no punishment. These scenarios endanger the mandated work of international organizations to supervise and regulate the rules of the war. It also disables the possibility of receiving correct information and enhance the possibility of belligerents and terrorist to hamper a democracy. This is certainly a global and unique problem for organizations such as ICRC, which have the responsibility to gather data and collect the necessary information to save civilian lives under IHL, and calls for actions targeting countries or warring factions that do not recognize the rules of war.

In this review, the rate of civilian casualties varied from 13 to 87% of the total casualties, depending on the type of conflict and might be concordant to that reported from earlier reports regarding wars in the literature (65–70%) (34, 35, 49–51). It is, however, clear that even 13% of the population involved in a little conflict, such as the one in Ukraine or Nagorno-Karabach, can result in over thousands injured, which alone can paralyze any local healthcare system. Together with the injuries from internal violence, riots, and assaults, the accumulated population in need of emergency help can overtime be comparable to the wars in the former Yugoslavia, and Syrian (47, 54–56, 58). The number of deaths, according to the same estimation, may vary up to 30% of the injured (32–35, 49). The figures from the domestic conflicts do not influence the total number of

civilian casualties and deaths markedly. However, its significance lies in the fact that multi-level confrontations and assaults result in resource scarcity, particularly within the healthcare systems, over a longer period, causing a rise in the number of deaths, and a need for serious medical decision-making (9–11, 18, 33, 34, 45, 96–98). Assuming that the number of deaths is a technical problem, the overwhelming number of injuries will be the cause of the collapse in all systems, requiring multiagency collaboration and a flexible surge capacity (96–98). The 90% increase in the global urban population in developing countries over the next two decades increases these nations' vulnerability to political and social unrest, violent crimes, terrorism, disasters, and armed conflicts (9, 10, 84). Medical planning for modern armed conflicts in the future should include an estimation of casualties in urban areas caused by domestic assaults, the use of drones, and terror attacks.

LIMITATIONS

The presented analysis has limitations.

- The majority of publications used in this review are in English, except a few translated Russian references. Consequently, some interesting data in other languages might be missing.
- Appropriate estimation of the casualties relies on complete data. There has been missing data regarding: The number of injuries and deaths among civilians and military staff, and some of the estimations were not reliable to use. Some major wars, such as the war between Iran and Iraq, were not included due to the lack of final data from the Iraqi side.
- There is a lack of standard definition of civilian casualty caused by armed conflicts.
- Additionally, there was neither complete information about casualties of air raids, nor the use of CBRN (Chemical, Biological, Radiological, Nuclear). Conflicts may also lead to the displacement of large populations into temporary settlements or camps with overcrowding and rudimentary shelters, inadequate safe water and sanitation, and increased exposure to disease vectors during the acute phase of the emergency. Thus, no available casualty figures for such incidents.
- In protracted and post-conflict situations, populations may have high rates of illness and mortality due to breakdown of health systems, flight of trained staff, failure of existing disease control programs, and destroyed infrastructure. These populations may be more vulnerable to infection and disease because of high levels of undernutrition or malnutrition, low vaccine coverage, or long-term stress.
- Finally, more and more defense policies identify the cyber (or information) domain and the human domain as to be included in multi-domain warfare (99, 100). Since warfare in cyber and human domains involve substantial pillars of civilian society, civilian contingencies planning requires casualty estimation in these warfare. Currently, the civilian and military casualty rates from cyber and human domain warfare is unavailable and could not be included in this review.

CONCLUSION

With an increasing number of public health emergencies and the lack of vital elements of life such as water and food, emerging armed conflicts seem to be inevitable (20, 87). This creates a unique and crucial situation in need of resource assessment and planning, which in turn requires a detailed study on the cause and impacts of the modern armed conflicts and clear access to the fields for supervision of the outcomes, casualty recording, and rules of the war (30, 45, 101, 102). The undeniable failure of international bodies to commit to humanitarian principles and the global disarray of the humanitarian system indicates the need for extensive reform in the current structure or a new global humanitarian body. Such afresh organization needs to employ a decentralized model to manage aid funds, assume coordination of international responses, resolve civil-military coordination, cater for people affected by both conflict and disasters, and professionalize the humanitarian career (101–103). Meanwhile, using the data presented in this study, even the lowest number of casualties inflicted by the modern armed conflicts may be enough to paralyze any healthcare system and indicates a need for new measures beyond a simple casualty estimation tool. Enhancing multiagency collaboration, empowering local preparedness and resilience capacity, and creating a flexible surge capacity might be new approaches, which together with a new international governing structure can achieve a better future for the next generation (30, 96–98).

This review aimed to discuss and examine the outcomes of traditional wars and modern armed conflicts and the possibility of foreseeing the medical impacts of 21st-century warfare on the civilian population concerning the number of casualties, mortality, and morbidity. Although it fails to present a simple casualty estimation algorithm, it highlighted the need for international engagement and each state's responsibility in following the rules of war. However, the most important factor remains to be the increased understanding of the nature of modern warfare and to plan for a scenario, when the needs exceed available resources, and decisive triage and adjusted resource utilization are mandatory.

RECOMMENDATIONS

1. The management of modern armed conflicts needs resources beyond casualty estimation tools. Multiagency collaboration, risk and vulnerability analysis and a high level of preparedness may improve the response in all phases of wars/conflicts.
2. Strengthening the international engagement, the role of humanitarian organizations, and the gravity of the International Humanitarian Law and Geneva Convention plays a crucial role in future conflicts. A new or a re-organized international governing agency is needed to hold all nations responsible for their actions by issuing, implementing, and supervising new restrictive approaches and international legal standards to production, and utilization of new weapons, and strategies. Furthermore, new strategies should be developed to combat new trends, such as the process of delegating the

performance of traditional state functions by states in favor of private military and security companies.

3. Empowering the local preparedness, risk reduction and resilience facilitates a proper response at the local level before additional resources can be obtained. Such readiness requires a functional public health and public service and an investment in education of local population. The cost will be far less than what the conflicts in general and modern armed conflict, in particular, may generate.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/**Supplementary Material**, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

AK-M provided the main framework, identified, and organized primary materials, and collaborated in writing the manuscript. FB reviewed and collaborated on the writing of the manuscript. KG and YR contributed to drafting sections of the manuscript. All authors have read and agreed to the published version of the manuscript.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.765261/full#supplementary-material

REFERENCES

1. Ogar JN, Ogar TE. An appraisal of globalization and its history. *Multidiscipline Res J.* (2019) 11:182–95. Available online at: https://www.proquest.com/scholarly-journals/appraisal-globalization-history/docview/2343679843/se-2?accountid=11162
2. Lerche III CO. *The Conflicts of Globalization*. *Int J Peace Stud.* (1998) 3. Available online at: https://www.gmu.edu/programs/icar/ijps/vol3_1/learch.htm (accessed August 26, 2021).
3. Smith RP. The economic costs of military conflicts. *J Peace Res.* (2013) 51:245–56. doi: 10.1177/0022343313496595
4. Khorram-Manesh A, Robinson Y, Boffard K, Örtenwall P. The history of Swedish military healthcare system and its path toward civilian-military collaboration from a total defense perspective. *Mil Med.* (2020) 185:e1492–8. doi: 10.1093/milmed/usaa071
5. Dumouchel P. *The Ambivalence of Scarcity and Other Essays*. Michigan State University Press (2014). Available online at: http://ebookcentral.proquest.com/lib/uu/detail.action?docID=3338367 (accessed August 26, 2021).
6. Amineh MP. *State, society and international relations in Asia. (ICAS Publications Series Edited Volumes; No 11*) Amsterdam, Netherlands: Amsterdam University Press (2010).
7. Beugelsdijk S, Welzel C. Dimensions and dynamics of national culture: synthesizing hofstede with inglehart. *J Cross-Cultural Psychol.* (2018) 49:1469–505. doi: 10.1177/0022022118798505
8. Szayna TS, Watts S, O'Mahomy A, Frederick B, Kavanagh J. *What are the trends in Armed Conflicts, and what do they mean for U.S. defense policy?* RAND Corporation (2017). Available online at: https://www.rand.org/pubs/research_reports/RR1904.html (accessed August 26, 2021).
9. Khorram-Manesh A. Europe on fire; medical management of terror attacks–new era and new considerations. *Bull Emerg Trauma.* (2016) 4:183-5.
10. Hirsch M, Carli P, Nizard R, Riou B, Baroudjian B, Baubet T, et al. The medical response to multisite terrorist attacks in Paris. *Lancet.* (2015) 386:2535–8. doi: 10.1016/S0140-6736(15)01063-6
11. Krause. From armed conflict to political violence: mapping & explaining conflict trends. *Daedalus.* (2016) 145:113–26. doi: 10.1162/DAED_a_00416
12. Burkle FM. Revisiting the battle of solferino: the worsening plight of civilian casualties in war and conflict. *Disaster Med Public Health Prep.* (2019) 13:837–41. doi: 10.1017/dmp.2019.77
13. Khorram-Manesh A, Goniewicz K, Burkle FM, Robinson Y. Review of military casualties in modern conflicts-the re-emergence of casualties from armored warfare. *Mil Med.* (2021). doi: 10.1093/milmed/usab108. [Epub ahead of print].
14. Kuhn GWS. *Ground forces battle casualty rate patterns. Uses in casualty estimation and simulation evaluation*. Logistics Management Institute (1992). Available online at: https://apps.dtic.mil/dtic/tr/fulltext/u2/a304904.pdf (accessed 20 Jan 2021). Accessed August 26, 2021.
15. Friedman JA. Using power laws to estimate conflict size. *J Conflict Resolut.* (2014) 59:1216–41. doi: 10.1177/0022002714530430
16. Spagat M, Mack A, Cooper T, Kreutz J.. Estimating war deaths: an arena of contestation. *J Conflict Resolut.* (2009) 53:934–50. doi: 10.1177/0022002709346253
17. Obermeyer Z, Murray CJL, Gakidou E. Fifty years fifty years of violent war deaths from Vietnam to Bosnia: analysis of data from the world health survey programme. *BMJ.* (2008) 336:1482–6. doi: 10.1136/bmj.a137
18. Levy BS, Sidel VW. Documenting the effects of armed conflict on population health. *Ann Rev Public Health.* (2016) 37:205–18. doi: 10.1146/annurev-publhealth-032315-021913
19. Phelan P. Fourth generation warfare and its challenges for the military and society. *Defence Stud.* (2011) 11:96–119. doi: 10.1080/14702436.2011.553105
20. TRADOC Pamphlet 525-3-1. *The U.S. Army in Multi-Domain Operations.* (2018). Available online at: https://www.tradoc.army.mil/News/Photos/igphoto/2002069773/ (accessed August 26, 2021).
21. Eaton JG. The beauty of asymmetry: an examination of the context and practice of asymmetric and unconventional warfare from a western/centrist perspective. *Defence Stud.* (2002) 2:51–82. doi: 10.1080/14702430212331391908
22. Cullen PJ, Reichborn-Kjennerud E. *Understanding Hybrid Warfare. 2017*. MCDC Countering Hybrid Warfare Project. Available online at: https://www.gov.uk/government/publications/countering-hybrid-warfare-project-understanding-hybrid-warfare (accessed August 26, 2021).
23. Tomes RR. Relearning counterinsurgency warfare. *Parameters.* (2004) 34:16–28. Available online at: https://press.armywarcollege.edu/parameters/vol34/iss1/11
24. Marshall A. From civil war to proxy war: past history and current dilemmas. *Small Wars Insurge.* (2016) 27:183–95. doi: 10.1080/09592318.2015.1129172
25. Razma, G. A modern warfare paradigm: reconsideration of combat power concept. *J Secur Sustain.* (2019) 8:435–52. doi: 10.9770/jssi.2019.8.30(12)
26. Khorram-Manesh A, Burkle FM. Disasters and public health emergencies—current perspectives in preparedness and response. *Sustainability.* (2020) 12:8561. doi: 10.3390/su12208561
27. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *BMJ.* (2021) 372:n71. doi: 10.1136/bmj.n71
28. Haby MM, Chapman E, Clark R, Barreto J, Reveiz L, Lavis JN, et al. What are the best methodologies for rapid reviews of the research evidence for evidence-informed decision making in health policy and practice: a rapid review. *Health Res Policy Syst.* (2016) 14:83. doi: 10.1186/s12961-016-0155-7
29. *Health Evidence Quality Assessment Tool*. Available online at: https://www.healthevidence.org/documents/our-appraisal-tools/QA_Tool&Dictionary_10Nov16.pdf (accessed August 26, 2021).

30. Arakelian M, Bekhrus K, Yarova L. Prohibited means and methods of armed conflicts. *Amazonia Investiga.* (2020) 9:349–55. doi: 10.34069/AI/2020.26.02.40
31. ICRC. *Protection of the civilian population. Overview*. Available online at: https://www.icrc.org/eng/what-we-do/protecting-civilians/overviewprotection-civilian-population.htm (accessed August 26, 2021).
32. Roberts A. Lives and statistics: are 90% of war victims civilians? *Survival.* (2010) 52:115–35. doi: 10.1080/00396338.2010.494880
33. Eckhardt W. Civilian deaths in wartime. *Bull Peace Propos*. (1989) 20:89–98. doi: 10.1177/096701068902000108
34. Cannon JW, Holena D, Geng, Z, Stewart IJ, Huang Y, Yang W, et al. Comprehensive analysis of combat casualty outcomes in US service members from the beginning of World War II to the end of operation enduring freedom. *J Trauma Acute Care Surg.* (2020) 89:8–15. doi: 10.1097/TA.0000000000002789
35. Johnson DE, Grissom A, Oliker O. *In the Middle of Fight – An Assessment of Medium-Armored Forces in Past Military Operations*. RAND Corporation, U.S.A. (2008). Available online at: https://www.rand.org/content/dam/rand/pubs/monographs/2008/RAND_MG709.pdf (accessed August 26, 2021).
36. Uppsala Conflict Data Program (UCDP). *Department of Peace and Conflict Research. Number of Conflicts*. Available online at: ucdp.uu.se (accessed August 26, 2021).
37. *UCDP Georeference Event Dataset*. Kaggle.com. Available online at: https://www.kaggle.com/mertcanyilmaz03/ucdp-ged-211 (accessed August 26, 2021).
38. International Committee of the Red Cross. *War & Law*. Available online at: https://www.icrc.org/en/war-and-law (accessed August 26, 2021).
39. International Institute of Humanitarian Law. *Humanitarian Commitment in Conflicts and Emergencies*. Available at: https://iihl.org/ (accessed August 26, 2021).
40. International Committee of the Red Cross. *Implementing International Humanitarian Law: From law to action*. Available online at: https://www.icrc.org/en/document/implementing-international-humanitarian-law-law-action (accessed August 26, 2021).
41. Burkle F. Declining public health protections within autocratic regimes: impact on global health security, infectious disease outbreaks, epidemics and pandemics. *Prehosp Disaster Med.* (2020) 35:237–46. doi: 10.1017/S1049023X20000424
42. United Nations Human Rights. *Guidance on Casualty Recording*. Available online at: https://www.ohchr.org/Documents/Publications/Guidance_on_Casualty_Recording.pdf (accessed August 26, 2021).
43. Conetta C. *The Wages of War. Iraqi Combatants and Noncombatants Fatalities in the 1991 Gulf War*. PDA (Project Defense Alternatives). Available online at: http://comw.org/pda/0310rm8ap2.html (accessed August 26, 2021).
44. Ri S, Blair AH, Kim CJ, Haar RJ. Attacks on healthcare facilities as an indicator of violence against civilians in Syria: an exploratory analysis of open-source data. *PLoS ONE.* (2019) 14:e0217905. doi: 10.1371/journal.pone.0217905
45. Friesendorf C. British operations among the people and civilian risk. *Small wars Insurgenc.* (2019) 30:615–40. doi: 10.1080/09592318.2019.1601866
46. Bissonnette CM. The definition of civilians in non-international armed conflicts. the perspective of armed groups. *J Int Human Legal Stud.* (2016) 7:129–55. doi: 10.1163/18781527-00701001
47. OCHA Special Focus. *Israeli-Palestinian Fatalities Since 2000- Key Trends*. Available online at: https://unispal.un.org/DPA/DPR/unispal.nsf/0/BE07C80CDA4579468525734800500272 (accessed August 26, 2021).
48. Dardagan H, Sloboda J. *Casualty Recording in and For the Modern Age: Why Standards Matter*. Human Law Policy (2016). Available online at: https://blogs.icrc.org/law-and-policy/2016/11/08/casualty-recording-standards/ (accessed August 26, 2021).
49. Jones DR. *Large Scale Combat Operations, Casualties, and the All-Volunteer Force. School of Advanced Military Studies. US Army Command and General Staff College. Fort Leavenworth*, Kansas (2019). Available online at: https://apps.dtic.mil/sti/pdfs/AD1083499.pdf (accessed August 26, 2021).
50. Millett A. *Korean War. Britannica.* (2021). Available online at: https://wwwbritannicacom/event/Korean-War (accessed August 26, 2021).
51. Spector RH. *Vietnam War. Britannica.* (2021). Available online at: https://wwwbritannicacom/event/Vietnam-War (accessed August 26, 2021).
52. Baudrillard J. *The Gulf war*. London: Power Publisher (1995).
53. Burkle FM, Newland C, Orebaugh S, Blood CG. Emergency medicine in the persian gulf war–part 2: triage methodology and lessons learned. *Ann Emerg Med.* (1994) 23:748–54. doi: 10.1016/S0196-0644(94)70310-8
54. International Center for Transitional Justice. *Transitional Justice for Former Yugoslavia.* (2009). Available online at: https://www.ictj.org/sites/default/files/ICTJ-FormerYugoslavia-Justice-Facts-2009-English.pdf (accessed August 26, 2021).
55. Toal G, Dahlman CT. Bosnia Remade: Ethnic Cleansing and its Reversal. Oxford University Press. (2011) 136. doi: 10.1093/acprof:oso/9780199730360.001.0001
56. Demolli H. Criminal judicial qualification and prosecution in the Racak case according to national and international legislation. In: Aertsen, Ivo; Jana A, Holger-C R, Marta V, Kris V, editors. *Restoring Justice after Large-scale Violent Conflicts Routledge.* Abingdon, VA; New York, NY: Routledge (2013).
57. WATSON Institute. *20 Years of War. Human Cost of Post 9/11 wars*. Available online at: https://watson.brown.edu/costsofwar/files/cow/imce/papers/2019/Direct%20War%20Deaths%20COW%20Estimate%20November%2013%202019%20FINAL.pdf (accessed August 26, 2021).
58. Human Rights Watch. Syria. *World report.* (2019). Available online at: https://www.hrw.org/world-report/2019/country-chapters/syria (accessed August 26, 2021).
59. New America Foundation. *Counter Terrorism – The Year of the Drone*. Available online at: https://web.archive.org/web/20110830213657/http://counterterrorism.newamerica.net/drones (accessed August 26, 2021).
60. Krivosjejev. GF. *Rossija i SSSR v voijnakh 20 veka. – Poteri Vooryzjennykh* Sil–Statistitjeskoje Isledovanije Olma-Press: Moskva, (2001). Available online at: https://connections-qj.org/article/rossiya-i-sssr-v-voynakh-xx-veka-poteri-vooruzhennykh-sil-statisticheskoe-issledovanie (accessed August 26, 2021).
61. Malek M. Russia's asymmetric wars in chechnya since 1994. *Connections: Quarter J.* (2009) 8:81–98. doi: 10.11610/Connections.08.4.05
62. Independent (NESAVISAMAYA). *War and Armies*. Available online at: https://www.ng.ru/ (accessed August 26, 2021).
63. Padourek J, Mares M. The threats of russian influence and terrorism within national security strategies of the visegrad four. *J Slavic Mil Stud.* (2020) 33:173–97. doi: 10.1080/13518046.2020.1763129
64. OHCHR. *Report On the Human Rights Situation in Ukraine 16 November 2019 to February 2020*. Available online at: https://www.ohchr.org/Documents/Countries/UA/29thReportUkraine_EN.pdf (accessed August 26, 2021).
65. OHCHR. *Report On the Human Rights Situation in Ukraine 16 February-31 July 2020*. Available online at: https://www.ohchr.org/Documents/Countries/UA/30thReportUkraine_EN.pdf (accessed August 26, 2021).
66. Human Rights Ombudsman in the Donetsk People's Republic. *The Overview of the Current Social and Humanitarian Situation in the Territory of the Donetsk People's Republic As a Result of Hostilities.* (2020). Available online at: http://eng.ombudsmandnr.ru/the-overview-of-the-current-social-and-humanitarian-situation-in-the-territory-of-the-donetsk-peoples-republic-as-a-result-of-hostilities-between-8-and-14-february-2020/ (accessed August 26, 2021).
67. Semercioglu H. The new balance of power in the southern Caucasus in the context of the Nagorno Karabakh conflict in 2020. *R&S-Res Stud Anatolia J.* (2021) 4:49–60. doi: 10.33723/rs.842487
68. Mallonee S, Shariat S, Stennies G, Waxweiler R, Hogan D, Jordan F. Physical injuries and fatalities resulting from the Oklahoma City bombing. *JAMA*. (1996) 7:382–7. doi: 10.1001/jama.1996.03540050042021
69. National Commission on Terrorist Attacks Upon The United States. *The 9/11 Commission Report*. Available online at: https://govinfo.library.unt.edu/911/report/911Report_Exec.htm (accessed August 26, 2021).
70. de Ceballos JP, Turégano-Fuentes F, Perez-Diaz D, Sanz-Sanchez M, Martin-Llorente C, Guerrero-Sanz JE, et al. 11 March 2004: the terrorist bomb explosions in Madrid, Spain–an analysis of the logistics, injuries sustained and clinical management of casualties treated at the closest hospital. *Crit Care.* (2005) 9:104–11. doi: 10.1186/cc29

71. Turégano-Fuentes F, Pérez Diaz D. Medical response to the 2005 terrorist bombings in London. *Lancet*. (2006) 368:2188–9. doi: 10.1016/S0140-6736(06)69871-1
72. Gates JD, Arabian S, Biddinger P, Blansfield J, Burke P, Chung S, et al. The initial response to the Boston marathon bombing: lessons learned to prepare for the next disaster. *Ann Surg*. (2014) 260:960–6. doi: 10.1097/SLA.0000000000000914
73. Lasoen K. Indications and warning in Belgium. brussels is not delphi .*J Strategic Studies*. (2017) 40:927–62. doi: 10.1080/01402390.2017.1288111
74. Lozada MJ. Cai S, Li M, Davidson SL, Nix J, Ramsey G. The Las Vegas mass shooting: an analysis of blood component administration and blood bank donations. *J Trauma Acute Care Surg*. (2019) 86:128–33. doi: 10.1097/TA.0000000000002089
75. Srimal F. One *Year Since Easter Attacks in Sri Lanka*. Centre for Security and Strategy Studies (2020). Available online at: http://dspace.jgu.edu.in:8080/jspui/handle/10739/3723 (accessed August 26, 2021).
76. Williamson H, Murphy K. Animus toward Muslims and its association with public support for punitive counter-terrorism policies: did the Christchurch terrorist attack mitigate this association? *J Exp Criminol*. (2020). doi: 10.1007/s11292-020-09450-x. [Epub ahead of print].
77. Mazuchowski EL, Kotwal RS, Janak JC, Howard JT, Harcke HT, Montgomery HR, et al. Mortality review of US special operations command battle-injured fatalities. *J Trauma Acute Care Surg*. (2020) 88:686-95. doi: 10.1097/TA.0000000000002610
78. Cronin B. *BUGSPLAT: The Politics Of Collateral Damage In Western-Armed Conflicts*. New york, NY; Oxford: Oxford University Press (2018).
79. Grant KA, Kaussler B. The battle of Aleppo: external patrons and the victimization of civilians in civil war. *Small Wars Insurgen*. (2020) 31:1–22. doi: 10.1080/09592318.2020.1672959
80. Vautravers A. Military operations in Urban areas. *Int Rev Red Cross*. (2010) 92:878. doi: 10.1017/S1816383110000366
81. Posen B. Command of the commons: the military foundation of U.S. *Hegemony Int Secur*. (2003) 28:1. doi: 10.1162/016228803322427965
82. Gondusky JS, Reiter MP. Protecting military convoys in Iraq: an examination of battle injuries sustained by a mechanized battalion during operation Iraqi freedom II. *Mil Med*. (2005) 170:546–9. doi: 10.7205/MILMED.170.6.546
83. Cincotta RP, Engelman R, Anastasion D. *The Security Demographic: Population and Civil Conflict After the Cold War*. Population Action International. Washington DC, USA. Available online at: https://pai.org/wp-content/uploads/2012/01/The_Security_Demographic_Population_and_Civil_Conflict_After_the_Cold_War-1.pdf (accessed August 26, 2021).
84. Kaldor M. *New And Old Wars: Organised Violence In Global Era*. Wiley (2012).
85. Lind WS. *Understanding Fourth Generation War. Military Review*. (2004) 12–16. Available online at: http://www.au.af.mil/au/awc/awcgate/milreview/lind.pdf (accessed August 26, 2021).
86. Congressional Research Service. *American War and Military Operations Casualties: Lists and Statistics*. (2020). Available online at: https://fas.org/sgp/crs/natsec/RL32492.pdf (accessed August 26, 2021).
87. Fazal TM, Rasmussen T, Nelson P, Carlton PK. *How Long can the U.S. Military's Golden Hour Last? War on the Rocks*. (2018). Available online at: https://warontherocks.com/2018/10/how-long-can-the-u-s-militarys-golden-hour-last/ (accessed August 26, 2021).
88. Schoenfeld AJ, Dunn JC, Bader JO, Belmon PJ. The nature and extent of war injuries sustained by combat specialty personnel killed and wounded in Afghanistan and Iraq, 2003-2011. *J Trauma Acute care Surg*. (2013) 75:287–91. doi: 10.1097/TA.0b013e31829a0970
89. Hägerdahl N. *Starvation as Siege Tactics: Urban Warfare in Syria. Stud Conflict Terrorism*. (2020). doi: 10.1080/1057610X.2020.1816682
90. Shultz R, Dew A. *Insurgents, Terrorists, and Militias: The Warriors of Contemporary Combat*. New York, NY: Columbia University Press (2009).
91. Raborg PC. *Mechanized Might: The Story of Mechanized Warfare*. Pickle Partners Publishing (2017).
92. Oliker O. *Russia's Chechen Wars 1994–2000: Lessons From Urban Combat*. Santa Monica, CA: RAND Corporation (2001). Available online at: https://www.rand.org/pubs/monograph_reports/MR1289.html (accessed August 26, 2021).
93. Gurcan M. Ankara vs. the PKK: old war, new strategies. *Turk Policy Quarter*. (2016) 14. Available online at: http://turkishpolicy.com/article/784/ankara-vs-the-pkk-old-war-new-strategies
94. Konaev M. The future of urban warfare in the age of megacities. *Focus Strategique*. (2019) 88. Available online at: https://www.ifri.org/en/publications/etudes-de-lifri/focus-strategique/future-urban-warfare-age-megacities
95. Khorram-Manesh A. Facilitators and constrainers of civilian-military collaboration: the Swedish perspectives. *Eur J Trauma Emerg Surg*. (2020) 46:649–56. doi: 10.1007/s00068-018-1058-9
96. Khorram-Manesh A. Flexible surge capacity-public health, public education, and disaster management. *Health Promot Prospect*. (2020) 10:175–9. doi: 10.34172/hpp.2020.30
97. Khorram-Manesh A, Lönroth H, Rotter P, Wilhelmsson M, Aremyr J, Berner A, et al. Non-medical aspects of civilian-military collaboration in management of major incidents. *Eur J Trauma Emerg Surg*. (2017) 29:183–90. doi: 10.1007/s00068-017-0778-6
98. Nessen SC, Le TD, Gurney JM. Combat casualty care statistics as outcome measures for treatment on the battlefield: a review and reconstruction of the data. *Current Trauma Report*. (2019) 5:187–94. doi: 10.1007/s40719-019-00177-3
99. U.S. Special Operations Command. *Operating in the Human Domain*. Available online at: https://nsiteam:com/social/wp-content/uploads/2017/01/SOF-OHD-Concept-V1:0-3-Aug-15:pdf (accessed August 26, 2021).
100. Crowther G. The cyber domain. *Cyber Defense Rev*. (2017) 2:63–78. Available online at: https://cyberdefensereview.army.mil/Portals/6/Documents/CDR%20Journal%20Articles/The%20Cyber%20Domain_Crowther.pdf?ver=2018-07-31-093712-330
101. Canyon D, Burkle FM. The 2016 World Humanitarian Summit Report Card: Both Failing Marks and Substantive Gains for an Increasingly Globalized Humanitarian Landscape. *PLoS Curr*. (2016) 8:ecurrents.dis.a94dd3e2f84d0a5abc179add7286851c. doi: 10.1371/currents.dis.a94dd3e2f84d0a5abc179add7286851c
102. Burkle FM. Challenges of global public health emergencies: development of a health-crisis management framework. *Tohoku J Exp Med*. (2019) 249:33–41. doi: 10.1620/tjem.249.33
103. Burkle FM. United nations charter, chapter vii, article 43: now or never. *Disaster Med Public Health Prep*. (2019) 13:655–62. doi: 10.1017/dmp.2018.43

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

REVIEW
published: 08 November 2021
doi: 10.3389/fpubh.2021.764069

Analyzing Healthcare Facility Resilience: Scientometric Review and Knowledge Map

Lingzhi Li[1], *Shuni Liao*[1], *Jingfeng Yuan*[2]*, *Endong Wang*[3] *and Jianjun She*[1]

[1] *Research Center of Smart City, Nanjing Tech University, Nanjing, China,* [2] *Department of Construction and Real Estate, School of Civil Engineering, Southeast University, Nanjing, China,* [3] *Department of Sustainable Resources Management, State University of New York, Syracuse, NY, United States*

In contemporary "high-risk" society, unexpected disasters (epidemics and extreme weather) and chronic pressures (aging problems) put tremendous pressure on healthcare facilities. Enhancing the healthcare facilities' resilience ability to resist, absorb, and respond to disaster disruptions is urgent. This study presents a scientometric review for healthcare facility resilience research. A total of 374 relevant articles published between 2000 and 2020, collected from Web of Science (WoS) core collection database, Scopus database and MEDLINE database were reviewed and analyzed. The results indicated that research on resilience in healthcare facilities went through three development periods, and the research involved countries or institutions that are relatively scattered. The studies have been focused on the subject categories of engineering, public, environmental, and occupational health. The keywords of "resilience," "hospital," "disaster," "healthcare," and "healthcare facility" had the most frequency. Furthermore, based on the literature co-citation networks and content analysis, the detected seven co-citation clusters were grouped into four knowledge domains: climate change impact, strengthening resilience in response to war and epidemic, resilience assessment of healthcare facility, and the applications of information system. Moreover, the timeline view of literature reflected the evolution of each domain. Finally, a knowledge map for resilience of healthcare facilities was put forward, in which critical research contents, current knowledge gaps, and future research work were discussed. This contribution will promote researchers and practitioners to detect the hot topics, fill the knowledge gaps, and extend the body of research on resilience of healthcare facilities.

Keywords: healthcare facility, hospitals, resilience, bibliometrics, delivery of health care, knowledge map, epidemics, disasters

Edited by:
Jarle Løwe Sørensen, University of South-Eastern Norway, Norway

Reviewed by:
Pertti Juhani Hakkinen, National Center for Biotechnology Information (NLM), United States
Jörn Klein, University of South-Eastern Norway, Norway

***Correspondence:**
Jingfeng Yuan
jingfeng-yuan@outlook.com

Specialty section:
This article was submitted to Disaster and Emergency Medicine, a section of the journal Frontiers in Public Health

Received: *24 August 2021*
Accepted: *11 October 2021*
Published: *08 November 2021*

Citation:
Li L, Liao S, Yuan J, Wang E and She J (2021) Analyzing Healthcare Facility Resilience: Scientometric Review and Knowledge Map. Front. Public Health 9:764069. doi: 10.3389/fpubh.2021.764069

INTRODUCTION

In a modern "high-risk" society, the aging population is increasing at an astonishing rate, alongside many disasters that frequently occur, such as earthquakes, floods, hurricanes, and epidemics (1, 2). During disasters, healthcare facilities are critical emergency response resources because they are central to providing timely and good quality healthcare services for the injuries (3, 4). With a broader view, the healthcare facilities are regarded as an elaborate network of buildings, services and relevant public and private sectors for providing and delivering healthcare service for the general public (5), including the national/regional healthcare systems and the single healthcare

facilities (e.g., hospitals, clinics and community care centers) (3). A single healthcare facility is composed of a set of interdependent components, such as medical staff, medical resources, medical equipment, physical building structures and equipment systems [e.g., "heating, ventilation, and air conditioning (HVAC) system," elevators, and power systems] (6). The increasing healthcare demand and disaster events threaten healthcare facilities' functionality (7–11). In such a situation, healthcare facilities are expected to maintain or even increase their capacity to provide continuous healthcare service even if they are directly affected by disasters. Recently, the concept of "healthcare facility resilience" (HFR) has been highlighted in the disaster management lexicon. It's the ability to prepare for, manage (absorb and adapt) and learn from shocks (12). This concept provides a new thinking paradigm for facilitating the healthcare facilities' sustainable operation in the face of disaster disruptions.

Over the past decade, several articles have reviewed HFR-related research. Several scholars have discussed some of the hazards or disturbances that healthcare facilities may face. For example, from a management perspective, Hugelius et al. pointed out that the healthcare facility may suffer, such as the lack of information and resources to deal with mass casualties (13). In 2017, Curtis et al. focused on the impact of extreme weather, such as heat waves, cold waves, and floods, on healthcare facilities and health services in the UK (14). Some other scholars reviewed existing literature and discussed models that could be used to measure HFR. These models may be comprehensive scoring framework models for evaluating some key capabilities of hospitals (15). Conceptual models may also be used to display resilience, such as state-space, stress-strain curve, temporal dynamic, stretched systems, and variety-space (16). Some scholars have been concerned about the response of healthcare facilities to disturbances. For instance, Kost et al. discussed combining "geospatial point-of-care testing" to address public health challenges (17). The needs of the patient are often an essential consideration when responding (16). Recently, more scholars have focused on HFR, especially in the case of the COVID-19 crisis. Haldane et al. reviewed national primary care guidelines for responding to COVID-19 and discussed how they support the operation of healthcare facilities (18).

Although a few articles have reviewed HFR-related studies, most are limited to specific research content. For example, some of these articles focus on evaluating HFR (19), and some are limited to the influence of specific factors on HFR (20). Most of the literature relies on subjective judgment rather than quantitative methods to identify the research topic (14, 19, 21, 22). Therefore, conducting a comprehensive review of HFR-related literature using a quantitative and objective method is necessary. The scientometric analysis is a quantitative method, referred to as knowledge domain visualization and mapping, which provides a holistic view of a particular domain through analyzing published articles (23). Combined with thematic analysis, this study aims to use this technique to review and visualize HFR research systematically from 2000 to 2020. The analysis of countries, institutions, published years, keywords, and subject categories can help understand the overall research status. Combined analysis of citing articles (the selected articles) and cited articles (the references of citing articles) can help identify research hotspots and research frontiers. Citation analysis visualization technology displays the research status and evolution of the knowledge domain on the network map. Finally, a knowledge map of HFR that reveals the critical research parts, knowledge gaps, future directions was proposed.

METHODOLOGY

The research framework of this study is shown in **Figure 1**, which is divided into three steps.

The first step aims to collect enough relevant articles related to HFR research. As one of the most authoritative publication databases, Web of Science (WoS) core collection database, Scopus database and MEDLINE database were selected as the sources for scientometric analysis (24, 25). The searching formula were used to determine more appropriate articles, according to article types and criteria. Following that, the abstracts of the retrieved articles were thoroughly read, and the literatures were screened according to certain criteria.

As the size and scope of HFR studies have expanded, conducting manual scientometric analyses is almost impossible. As a convenient scientometric and visual analytic tool, CiteSpace software able to review the classic research theme and discover potential trends (26, 27). Thus, in the second step of this study, CiteSpace software 5.8.R1 is used to conduct scientometric analysis, including literature distribution analysis, co-occurrence analysis, and co-citation analysis. Critically, the research hotspot and research trend are discussed in each identified knowledge domain.

The final step is to develop the knowledge map of HFR studies, in which the critical research content and knowledge gaps will be discussed.

DATA COLLECTION

Detailed literature retrieval rules and exclusion strategies are as follows.

Literature Retrieval

The databases searched in WoS include WoS core collection databases (including Science Citation Index Expanded, Social Sciences Citation Index, Arts and Humanities Citation Index and Emerging Sources Citation Index) and MEDLINE database. After pre-analysis and comparison, the determined search schema for searching the WoS core collection database and MEDLINE database was as follows: TS = (resilien*) AND TS = (hospital* OR medical OR health* OR care) AND TS = (facility OR facilities OR asset* OR "built environment" OR "building portfolio" OR lifeline OR equipment OR device*). "TS" means the topic of an article, and "*" refers to a fuzzy search. In addition, the determined search schema for searching the Scopus database was as follows: TITLE-ABS-KEY (resilien*) AND TITLE-ABS-KEY (hospital* OR medical OR health* OR care) AND TITLE-ABS-KEY (facility OR facilities OR asset* OR lifeline OR "built environment" OR "building portfolio" OR equipment OR device*). Literature published before 2020 (including 2020) was

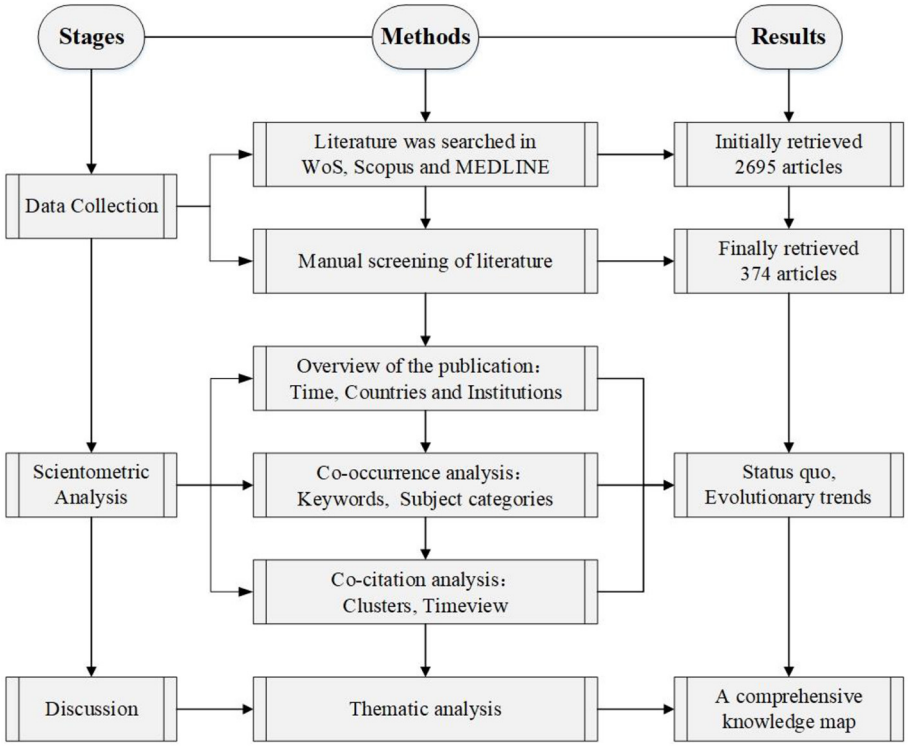


FIGURE 1 | Research framework.

searched from these three databases. The language is limited to English, and the type is confined to article. After data deduplication, 2,695 articles were obtained.

Exclusion Criteria

The retrieved results need to be reviewed to ensure that the selected articles meet the requirements for further analysis (28, 29). By reading the abstract, unrelated literature was excluded from detailed review and analysis according to the following criteria:

(1) Journals that have not been peer-reviewed will be excluded.
(2) Articles lacking references, authors, and the full text will be excluded.
(3) Repeated articles published in different journals with the same authorship will be excluded (only the oldest ones are retained).
(4) The articles focused on resilience but not the healthcare facility. These articles target psychological resilience (30), supply chain resilience (31), and the resilience of ecosystem (20).
(5) The terms in the search schema are used in different settings or had other irrelevant meanings. For example, "resilience" in Yin et al. (32) did not refer to the capability to respond disasters, maintain its most essential functions, and "bounce back" to the pre-event state (termed recovery) or to a new state of function (termed adaptation) (21) but described how the object moves or deforms under the action of external force.
(6) These articles focus on the research and development of medical devices or technologies to support healthcare services, but HFR is not directly related (33).

By further screening, 374 articles were eventually selected for scientometric analysis, among which there are 251 articles from the WoS core Collection database, 72 from Scopus database, and 51 from MEDLINE database. The period ranges from 2001 to 2020.

SCIENTOMETRIC ANALYSIS AND RESULTS

Overview of the Publication Year

Figure 2 shows the distribution of HFR-related articles over time from 2000 to 2020, illustrating that HFR research was thriving. In 2000–2007 the number of published articles (8 articles in total) was relatively small. Preliminary explorations were conducted during this period. In 2008–2014, the number of articles fluctuated between 5 and 15 (64 articles). This period belongs to the period of slow growth. Between 2015 and 2020 is the period of rapid growth, in which the number of published articles grew rapidly from 27 to 93. The number of articles during this period is 302, accounting for 80.75% of the total number of articles (374).

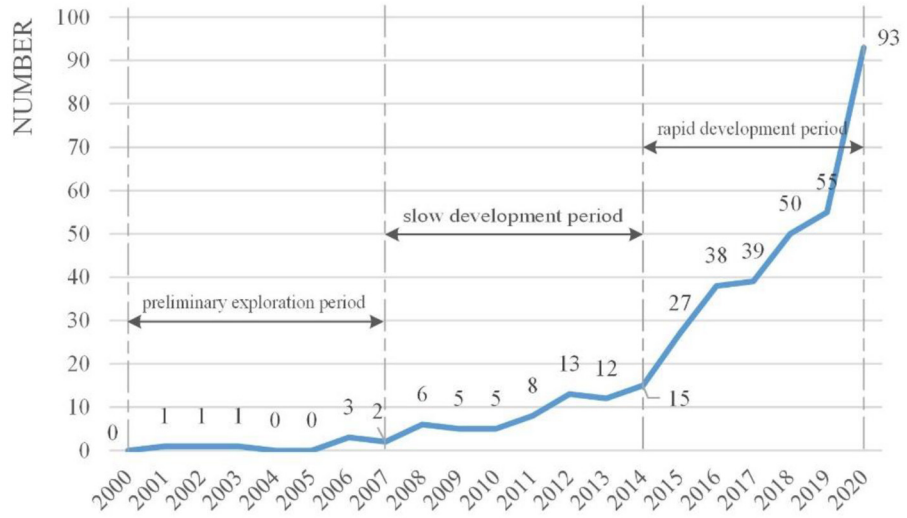


FIGURE 2 | Number of articles on HFR.

Overview of the Publication Countries and Publication Institutions

Figure 3 shows the countries and institutions' co-occurrence network diagram of HFR research. The network contains 244 nodes and 491 links. Among which, 138 nodes represent countries, and 106 nodes display institutions. The larger the node, the more articles are published in the country or institution (34). The top five are the United States (174, accounting for 46.52% of the total), the United Kingdom (67, constituting 19.91% of the total), Australia (41, occupying 10.96% of the total), Italy (36, taking up 9.63% of the total), and China (35, amounting to 9.36% of the total). It is apparent to see that the United States is far ahead in this field. The complex links between nodes indicate a common phenomenon of transnational cooperation in this area. The thicker the link, the more collaborations and the closer the connection between the countries. The purple circle shows that the United States, the United Kingdom, Canada, and Spain have played a crucial role in international cooperation. In general, the distribution of institutions is consistent with the distribution of countries (regions) (35). The United States has the most active research institutions on HFR, University of Washington (6). It is followed by London School of Hygiene and Tropical Medicine (5) and Politeco di Torino (5), which come from the United Kingdom and Italy with high publication outputs, respectively. Overall, institutions conducting and publishing HFR research are relatively scattered.

Subject Categories Co-occurrence Network

The subject category co-occurrence network is shown in **Figure 4**. The network consists of 168 nodes and 382 links, suggesting that HFR-related research covers 168 subject categories, illustrating that the research is interdisciplinary. The more articles were published in a particular subject area, the larger the node (36). The top five subject categories are engineering (65); public, environmental, and occupational health (63); humans (33); environmental sciences and ecology (28); engineering and civil science (23). In **Figure 4**, the link between nodes indicates that two topics appear at the same time in the same article. The thicker the link, the greater the frequency. In **Figure 4**, nodes with high centrality are marked by purple rings (35). Some nodes with high centrality in co-occurring subject categories network are delivery of health care (0.83), ergonomics (0.78), industrial (0.77), and engineering (0.66), which demonstrate that these subject categories are the major turning nodes linking the HFR research in different phases (35).

Keywords Co-occurrence Network

According to the articles selected from the two databases, the co-occurrence network of keywords was generated, as shown in **Figure 5**. This network contains 270 nodes and 639 links, which shows 270 keywords. Node size indicates keyword frequency. The top five high-frequency keywords are "resilience" (frequency = 86), "hospital" (frequency = 63), "disaster" (frequency = 41), "healthcare" (frequency = 37), and "healthcare facility" (frequency = 31). The links between nodes are complicated. Multiple keywords frequently appear together in the same literature and are closely interrelated.

Literature Co-citation Network and Timeline View

This study used the LLR algorithm to generate the literature co-cited network (**Figure 6**). This network consists of 197 nodes and 418 links. The modularity is 0.8646, indicating that these co-citation clusters can define the research areas of HFR (37). The mean silhouette is 0.8857 (>0.5), so the clustering result is reasonable (26). The silhouette of the major clusters discussed in the study is all over 0.9, reflecting the high homogeneity of

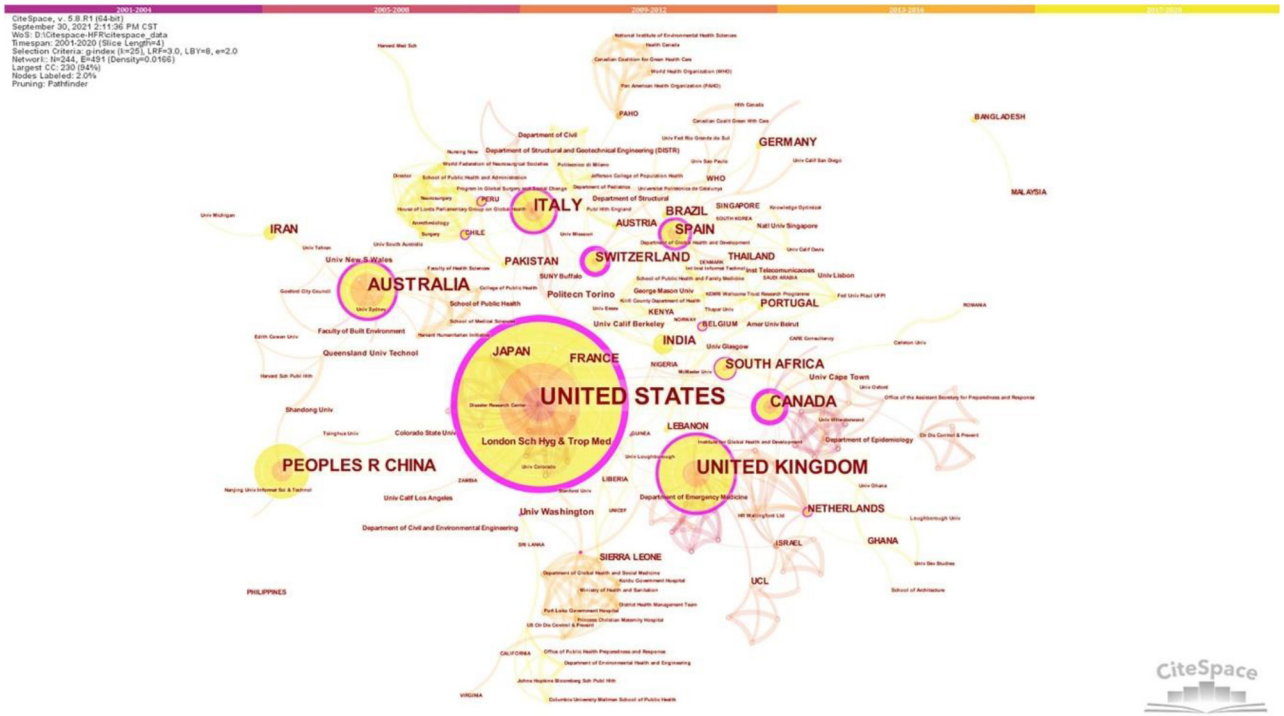


FIGURE 3 | Countries and institutions co-occurrence network.

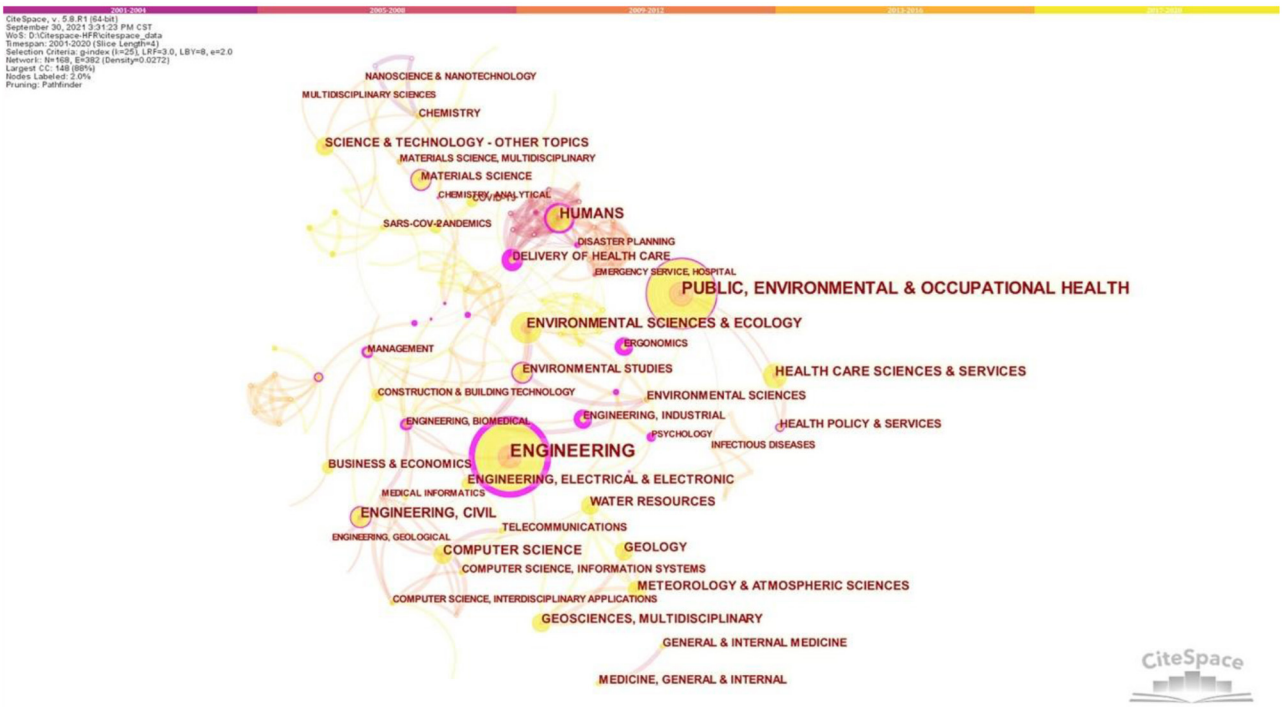


FIGURE 4 | Subject categories co-occurrence network.

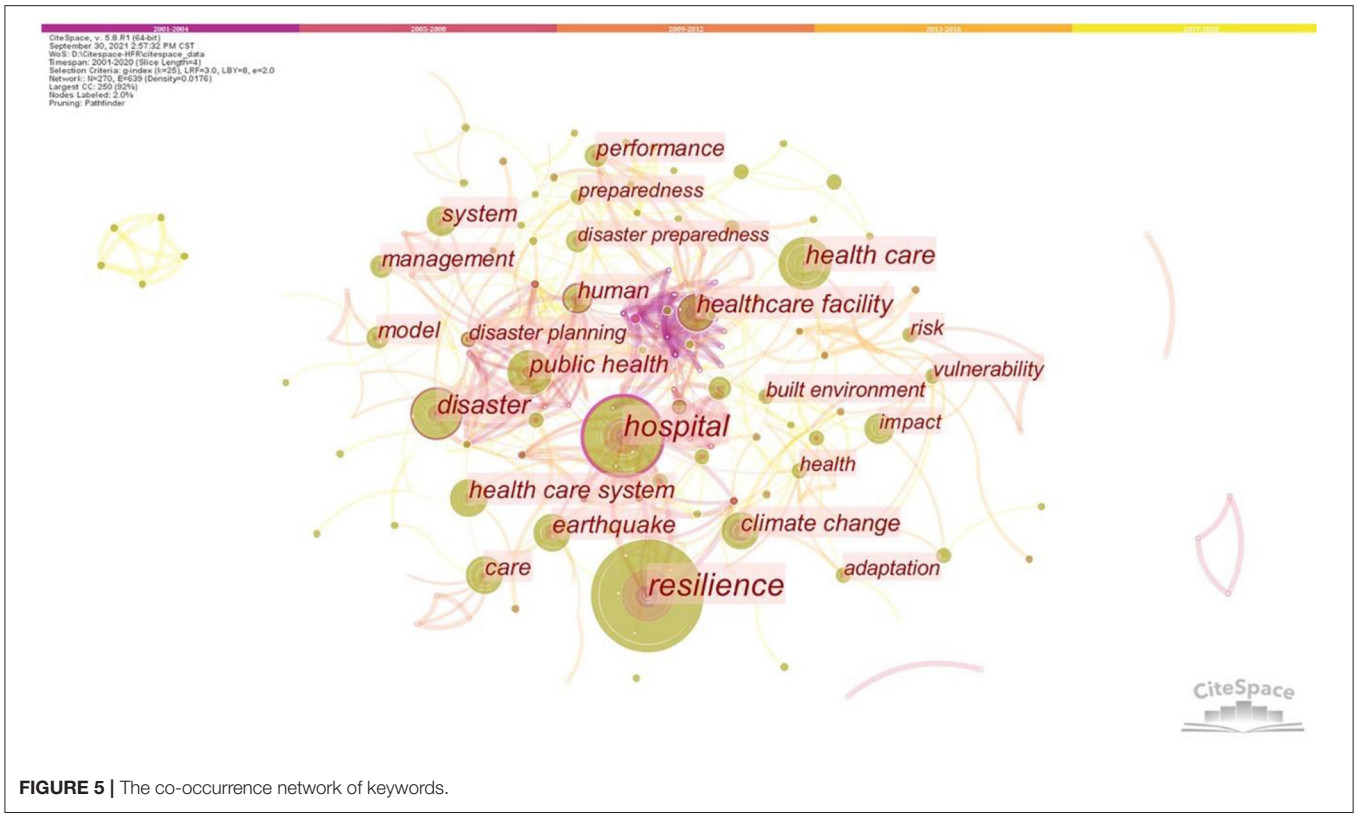


FIGURE 5 | The co-occurrence network of keywords.

the network (38). After excluding the small clusters with a small number of articles (the number < 10), 7 clusters (#0 – #6) were finally identified in the literature co-cited network. The label of each cluster was determined by the citing literature in the cluster (26).

Furthermore, the timeline view (**Figure 7**) reflects the evolution of HFR knowledge, in which the co-citation outbreak of each cluster was shown explicitly. The nodes of high centrality are marked by purple circles. The larger the node, the more times the document is cited (38). The more highly cited articles in a cluster, the more important the cluster is. In recent years, no HFR literature with high citation frequency has been found; thus, citation frequency needs time to accumulate (38, 39). Given the impact on the evolution of HFR knowledge, the literature with high centrality and high citations should be paid attention to. Linking different clusters can also be a potential turning point (34). Furthermore, in different clusters, an article may be highly cited literature and highly citing literature. *Seismic resilience of a hospital system*, published by Cimellaro et al. (40), is an example. It is highly cited literature at #0 and the highly citing literature at #6. Such articles can also be a potential turning point.

On the basis of the main research content, seven clusters are classified into four knowledge domains (Numbered as KD1-KD4) as follows.

(1) KD1 "climate change" = cluster #1 "extreme weather events" + cluster #5 "heat waves"

The knowledge domain KD1 focuses on the impact of extreme weather (heat waves, low temperatures, floods, and hurricanes) on healthcare facilities. Measures to reduce the negative effect of climate change are also discussed. Of all the extreme weather, scholars are mainly concerned with extreme heat due to serious climate change problems. This phenomenon can also be seen from the cited and citing references in this domain.

The most cited article in this domain was published by Lomas et al. (41), who proposed the renovation plans for the British hospital wards to cope with the elevated temperatures and achieve energy savings. In other highly cited articles, Short et al. and Lomas and Giridharan, worked on adapting hospital buildings for climate change with the application of data monitoring and building modeling technologies (42, 43). Hajat et al. and Nitschke et al. discussed the effects of heat waves on human health and the increased demand for healthcare facilities (44, 45). Morbidity, demand for ambulance services, demand for emergency medical services, hospitalization rates, and other indicators can be used to measure the impact on human health (14, 44, 45). Furthermore, indicators such as demand for ambulance services, hospitalization rates, and demand for emergency medical services can also be used to reflect the impact on health facilities (44, 45). The most citing article was published by Chand and Loosemore in 2016 (46), which discussed the vulnerability of healthcare facilities in geographical environment, built environment and organizational management under extreme weather. Six improvements were proposed to strengthen disaster management and improve HFR. Additionally, Curtis et al. (14) discussed the impact of climate change on the health and social care system given the healthcare services' provision and demand. Possible resilience enhancement

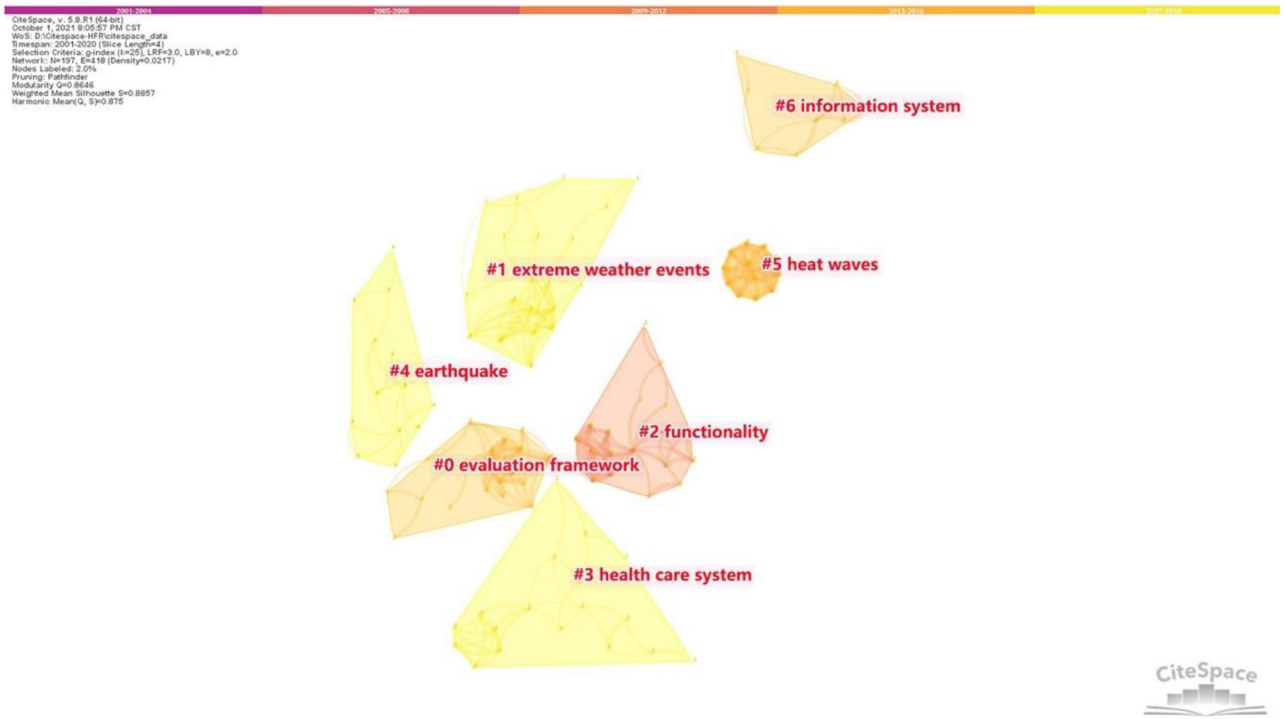


FIGURE 6 | Literature co-citation network.

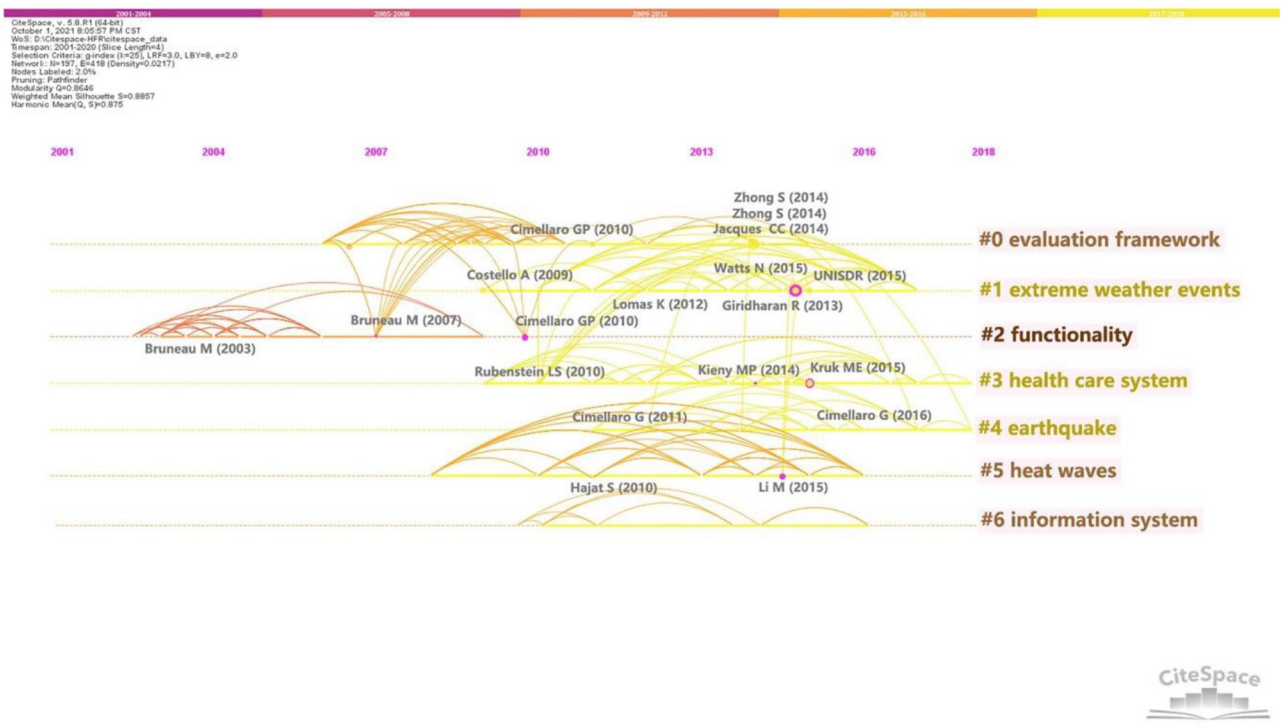


FIGURE 7 | Timeline view of co-citation clusters.

measures, such as renovating hospitals to improve thermal comfort and increasing capacity for population risk identification and health awareness, are also discussed (14). Codjoe et al. analyzed the vulnerability of healthcare facilities and health services to flood and heat wave, and proposed measures to improve HFR in low-income areas (47). Extreme weather can cut off power supplies to healthcare facilities, which will disrupt the continuity of healthcare provision (48). Therefore, power outage problems have attracted the attention of researchers (49–51). A series of response measures were put forward, including preparing emergency generators (48, 50), better detection of power supply failures (49), the rise of distributed energy (52), and microgrids (53), etc.

From the timeline view (**Figure 7**), since 2008, the knowledge domain KD1 has begun to appear in highly influential articles. In 2009 and 2010, Costello et al. (54) and Hajat et al. (44) discussed the impact of climate change on health and the impact of surging demand on health care facilities. In 2012 and 2013, Lomas et al. (41), and Giridharan et al. (55) discussed the coping measures of hospital buildings and hospital spaces to elevated temperatures. In 2015, Li et al. discussed the impact of heat waves on morbidity and pointed out the need to establish data collection and monitoring systems to guide actions against climate change (56). In the same year, Watts et al. proposed a range of policy responses to climate change (57). *Sendai Framework for Disaster Risk Reduction 2015-2030* was proposed in 2015, in which public health and climate change are important parts (58). It can be seen from the recent citing literature that people in recent years are paying more attention to the energy issues and sustainability issues induced by climate change (52). With the frequent threat of global climate change, the term "resilience" is increasingly discussed in healthcare facilities' operation areas around climate change adaptation and disaster risk reduction (59, 60). A series of resilience measures to climate change adaptation are studied in recent years, including enhanced energy supply management, establishing early warning systems to collect climate and morbidity information, ensuring environmental sustainability of healthcare facilities, etc. (14, 57, 61).

(2) KD2 "strengthening resilience in response to war and epidemic" = cluster #3 "health care system"

This knowledge domain focuses on the impact of wars and epidemics on healthcare systems and measures to improve resilience. In particular, of all the wars and epidemics, the Syrian war and the Ebola virus outbreak are the two major disasters discussed in HFR research.

Epidemic and war lead to a shortage of resources and a rise in mortality. Furthermore, these two disturbances can often be combined to disrupt the supply of healthcare services. During the war, the use of violence to destroy healthcare facilities is increasingly common (62, 63). The destruction of roads, the breakdown of communications, and the threat of death from the war made it difficult for healthcare facilities to obtain adequate resources timely and prevented patients from being able or afraid to go to hospitals for treatment (64–66). The scarcity of health care services and the increasing number of patients further promote the outbreak of epidemics and ultimately lead to the collapse of healthcare systems (65, 66). In this case, many scholars have studied how to improve HFR to ensure the accessibility of healthcare services during wars and epidemics. The most cited article in this domain is published by Kruk et al. in 2015, who pointed out that a resilient healthcare system should identify threats as quickly as possible, be multi-layered, and have broad coverage (67). Furthermore, a resilient healthcare system should have strong links and adequate communication with external organizations or countries (67, 68). During outbreaks of war and infectious diseases, the concept of resilient health systems has been studied in greater depth (69). People pay more attention to the positive role that individual facilities within the system can play (69). In highly cited articles, Gilson et al. (70) and Kieny et al. (71) also believe that giving full play to the role of leaders in the healthcare system, and strengthening the information exchange within and outside the healthcare system will be powerful measures. In the most citing literature, Jamal et al. (66) pointed out that providing physical and psychological support to employees, ensuring organizational flexibility, and establishing good collaboration and communication mechanisms are key points. In the highly citing literature published by Douedari et al. (72), strategic vision, participation, transparency, responsiveness, equity, effectiveness accountability were considered as critical elements for healthcare system governance. In addition, Fouad et al. (62) and Raven et al. (73) stated it was necessary to provide a safe working environment and appropriate incentives for front-line health workers (62, 73). These measures will help them relieve the psychological pressure, and subsequently the continuity of healthcare provision can be ensured to some extent (71). In addition, many cited articles (67, 68) and citing articles (62, 74) emphasized the necessity of establishing an information monitoring system, which is important for the prevention and control of epidemic outbreaks.

The timeline view (**Figure 7**) shows KD2 active since 2009. A highly cited paper in this knowledge domain was published by Rubenstein and Bittle (75) in 2010 which highlighted the importance of protecting healthcare facilities and medical staff in conflict and discussed the possible effective strategies. In 2014 and 2015, nodes with high centrality appeared. These two articles were published by Kieny et al. in 2014 (71) and Kruk et al. in 2015 (67), respectively. They all discussed the impact of the Ebola virus outbreak on healthcare systems and measures to improve resilience of systems. This may be related to the spread of Ebola virus from 2014 to 2015. The content of discussion in this knowledge domain does not evolve and change obviously.

(3) KD3 "resilience assessment" (ND3) = cluster #0 "evaluation framework" + #2 "functionality" + cluster #4 "earthquake"

In this domain, researchers applied various approaches to assess HFR and proposed several measures to improve resilience in the face of disasters (6). "Evaluation framework" consist of a number of resilience measures or indicators for resilience measurement (15, 76). "Functionality" is the most commonly used metrics for describing HFR (77). Particularly, the earthquake is the popular disaster discussed in this knowledge domain.

In the most cited literature, Jacques et al. (78) in 2014 used fault tree analysis to identify factors that affect critical hospital services, namely, non-structural component failures and external utility supply disruptions. In addition to the above two factors, Mitrani-Reiser et al. (79) and Kirsch et al. (10) also considered the damage to structural components, equipment and workers. Achour et al. (80) focused on the influence of public utilities, in which the impact of utility disruptions on healthcare facility was quantified. Some research utilized the modeling-based approach to assess HFR. For example, Cimellaro et al. (3) in 2011 and Cimellaro et al. (8) in 2016 proposed meta-models and discrete event simulation (DES) to assess resilience in the emergency department. In these studies, "patient waiting time" was used as a final measure of resilience (3, 8). Furthermore, the most citing article was published by Zhong et al. (15) in 2014, who developed a framework with eight areas to measure the resilience of hospitals to disasters. On this basis, factor analysis was conducted to extract four key capabilities (including emergency medical response capability, disaster management mechanisms, hospital infrastructural safety, and disaster resources) to measure HFR (15). In the same year, another framework was proposed by Zhong et al. (21) using literature review method. The key assessment areas are classified as robustness, redundancy, resourcefulness and rapidity. The functionality or performance of healthcare facilities is a commonly used resilience measure in many HFR assessment methods (77). In the highly cited articles, Cimellaro et al. (81) and Cimelaro et al. (40) quantified HFR by considering the loss and recovery phases of a healthcare facility's functionality. Furthermore, Khanmohammadi et al. (6) simulated the dynamic recovery process of hospital function after earthquakes. This model can help decision-makers assess the resilience of post-earthquake hospitals and determine the optimal use of available resources (to help hospitals recover their functions) (6). The citing article, Cimellaro et al. in 2019, used "patient waiting time" to measure the performance of a healthcare facility network in emergencies and proposed two resilience improvement strategies, namely, reallocating existing resources and building new emergency departments (82).

From the timeline view (**Figure 7**), the citation phenomenon appears among #0 "evaluation framework," #2 "functionality," #4 "earthquake," which is sufficient to illustrate the intimate relationship between these three clusters. Among the three clusters, #2 "functionality" appeared the earliest among the top seven clusters, in which the citation outbreak appeared since 2003. The first widely cited article in this domain was published by Bruneau et al. (83) in 2003. In this study, "4R," namely robustness, redundancy, resourcefulness, and rapidity, is used to summarize the concept of resilience for the first time (83). Since then, scholars have proposed many ways to evaluate HFR. Bruneau and Reinhorn (84) in 2007, Cimellaro et al. (81), and Cimellaro et al. (40) used probability functions to quantify the loss and recovery of performance/function in healthcare facilities. It is also common to identify key indicators and develop a framework model for assessment by combing the key capabilities of HFR (15, 21). Furthermore, scholars tend to evaluate HFR by modeling the interactions and behavioral changes of sub-systems within a facility, such as Cimellaro et al. (3) in 2011 and Cimellaro et al. (8) in 2016. With the deepening of the research, the research content gradually expanded from individual healthcare facilities to healthcare networks or systems. In 2010, Cimellaro et al. (40) assumed that the performance of healthcare networks was simply equal to the aggregation of individual facilities' performance. Based on an empirical study, Jacques et al. (78) in 2014 further discussed the positive effect of service sharing among hospitals on healthcare network performance. A recent citing article (85), which Hassan and Mahmoud published in 2020, established a framework model for assessing the resilience of post-earthquake healthcare systems. This model considered the quality and quantity of services provided by the hospitals, the demand and arrival rate of patients on the hospitals, and the interaction between hospitals and other infrastructures (85). HFR assessment studies are increasingly complex and profound.

(4) KD4 "applications of information system" (ND4) = cluster #6 "information system"

This knowledge domain mainly discusses the application of technologies in the healthcare industry. With the help of these technologies, healthcare facilities can process large amounts of information quickly, and provide more efficient, higher-quality services to more patients in less time.

A common application area with technologies is optimizing the layout of healthcare facilities. For one thing, in resource-constrained settings, well-located facilities can greatly improve access to health services, ensuring accessibility at the community or city level while making full use of resources. The most cited article (86) by Ferguson et al. in 2016 used Geographic Information System (GIS) to identify critical and efficient paths for patients accessing health services. Healthcare facilities are prioritized at the sites with large population congregations and intersection of these paths (86, 87). For another, with the help of GIS, the location of healthcare facilities can avoid low-lying areas, flood and other disasters or reduce the probability of such events (47). Another application area discussed frequently is decision support for resource allocation. It is reflected in prioritizing the provision of resources to core functional components to ensure service provision, and facilitating the reasonable matching of resources and demands to speed up the recovery of facility performance. In an article published in 2010 by Paturas et al. (88), a Hospital Emergency Support Functions (HESF) model based on the personnel database was developed urgently to review all functions and staff in the hospital. The most suitable personnel will be assigned to key positions based on the importance of the function and the capacities of the people. Additionally, medical diagnosis and treatment is popular in recent years. The COVID-19 outbreak has boosted popularity of telemedicine technologies. As the citing article (18) by Haldane et al. in 2020 and the citing article (89) by Bhaskar et al. in 2020 pointed out, telemedicine can ensure physical distance between people, reduce the route of transmission of the virus, and provide health services continuously.

From the timeline view (**Figure 7**), the knowledge domain KD4 began to rise around 2010, which is a relatively new research topic. The development of technologies also takes time to accumulate. These may be the reasons why this domain has no

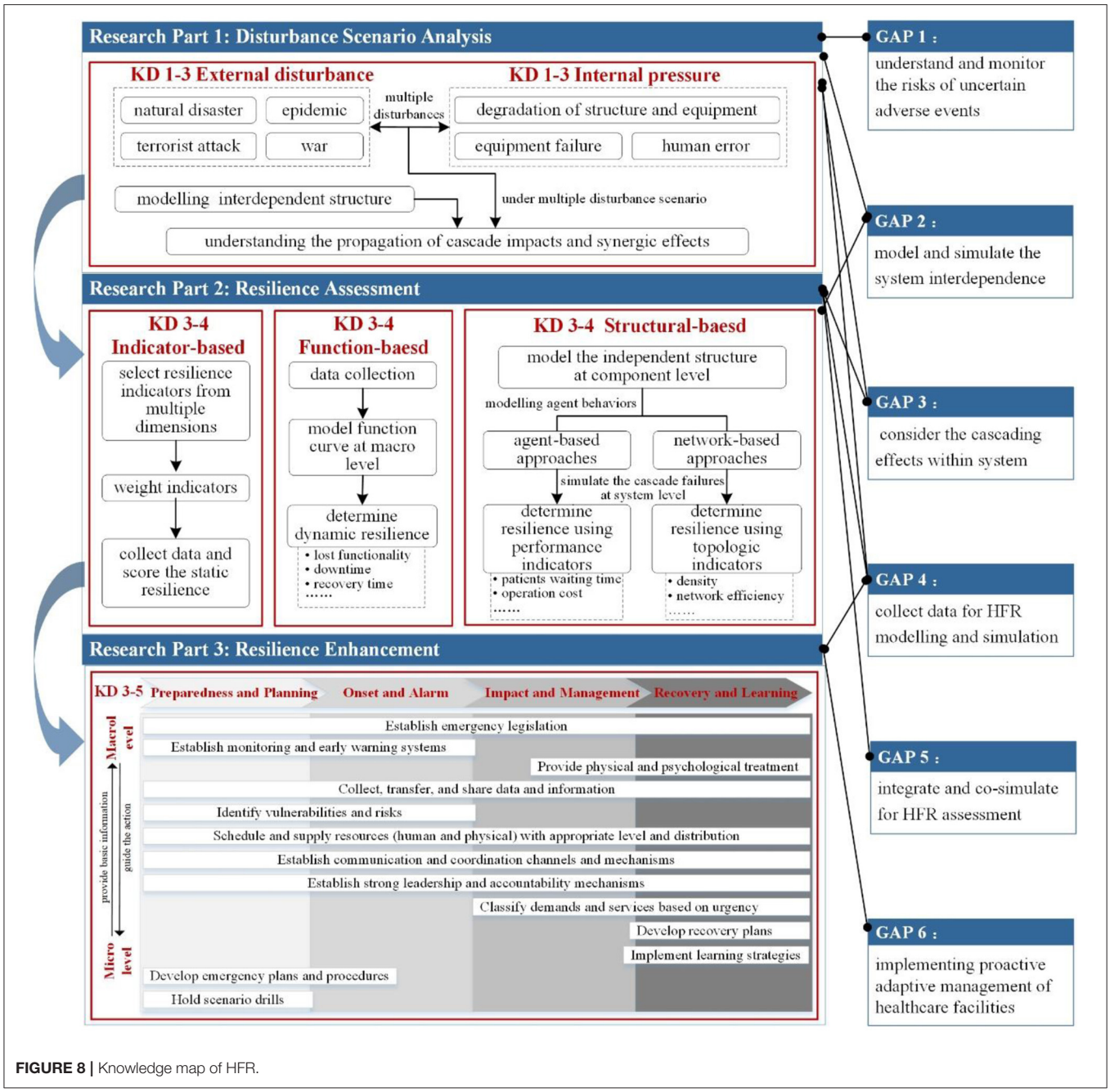


FIGURE 8 | Knowledge map of HFR.

large citation outbreak and high centrality nodes. In recent cited literature, COVID-19 is an unshirkable research content (18, 90). They illustrate the impact of epidemics outbreaks on the use of technologies in healthcare facilities. With the advent of the data age, the everchanging science and technology will make this field of knowledge active for a long time.

DISCUSSION

Despite the considerable amount of HFR studies, no earlier effort has been given to existing aggregate findings quantitatively and comprehensively to our best knowledge. Thus, a comprehensive knowledge map for HFR is put forward (**Figure 8**) based on the aforementioned scientometric review and deep content analysis. The following part discussed the critical research parts, current research gaps, and future work.

Critical Research Parts of HFR

As shown in **Figure 8**, this framework depicts three critical research parts of HFR: disturbance scenario analysis, resilience assessment, and resilience enhancement. Their states are described as follows.

Disturbance Scenario Analysis

When addressing the HFR issues, the researchers must primarily clarify what the healthcare facilities are resilient to (91). Specifically, which resilience strategies should be followed depends on the specific country context and the type of disturbances (12). Different economic-level countries focused on different disasters due to their specific regions, various healthcare level and infrastructure conditions, and diverse political conditions (92). Though content analysis, we stratified the data (collected articles) with regard to the involved countries with different economic level and their concerned disasters (**Table 1**) (93). Of the total 55 involved countries, there were 17 high-income countries (30.91%), 11 upper-middle income countries (20%), 17 lower-middle income countries (30.91%), and 10 low-income countries (18.18%), respectively. It appears that the healthcare sector of these countries is largely focused on acute shocks. High-income and middle-income (upper-middle and lower-middle) countries are more concerned about climate change and natural disasters, such as earthquakes, hurricanes, floods, etc., while low-income countries mostly discussed about Ebola and conflicts. Recently, with the emergence and rapid spread of COVID-19, more studies are trying to discuss the national response experience of the high-income countries and upper-middle income countries, and aiming to draw lessons from healthcare system that have proved more successful (12). Clearly, climate change issues, natural disasters and epidemics will severely test the healthcare facilities in all countries around the world in future. Understanding the pathways of various disturbances not only helps decision-makers prepare for problems but also manage better when they happen.

Disturbance scenario analysis characterizes the type, severity, occurrence time, and potential risks. For healthcare facilities, the disturbances are classified into external disasters (e.g., earthquakes, large floods, epidemic, and war) and internal pressures (e.g., equipment failure and human error) (47, 62, 94). The external disasters will cause the healthcare facilities' internal structural failure directly or interrupt the supply of external lifeline services (e.g., electric, water, communication, and gas) for healthcare facilities. Evidence shows that disasters are not always isolated events and usually occur in complex combinations (95). For instance, in 2008, the Wenchuan Earthquake in China was followed by floods and landslides (96, 97). Following such complex disturbances, healthcare facilities face significant operation challenges regarding the continuity of healthcare service (80). Considering the different disturbance scenarios, Zhao et al. and Ouyang et al. presented two basic scenario modes: single-disruption scenario and multiple-disruptions scenario (98, 99). The latter mode shows the impact of the initial event and its ensuring events on the performance of the infrastructure system. Some studies have focused on the single disturbance event in terms of healthcare facility resilience. For example, Bruneau and Reinhorn (84) in 2007 discussed seismic resilience in acute care facilities. Few studies began to consider the multiple disruption scenarios in the healthcare facility context. For instance, Qirbi and Ismail (100) in 2017 discussed the impact of wars and epidemics on healthcare facilities in Yemen.

TABLE 1 | Data stratification based on countries' economic level and concerned disasters.

Disasters	Low-income countries	Lower-middle income countries	Upper-middle income countries	High-income countries
Heat wave	1	2	1	6
Low temperature				3
Flood	2	5	3	8
Hurricane		3	2	9
Earthquake		5	6	22
Tsunami		1		2
General climate change issues/natural disasters	3	16	7	25
COVID-19	1	1	5	10
Ebola	18	1	6	3
General epidemics	5	5	6	4
Refugee	2	2		
Conflict	10	1	3	
Terrorist attack	2		2	1
Economic crisis		1		2
General disasters	1	2	9	19

Furthermore, the disturbance scenario analysis should understand how the disturbances influence the system (101). Such analysis should involve analyzing the system structure and clarifying the initial and subsequent failure caused by disturbances. The healthcare facility can maintain its normal function owing to external lifeline services (e.g., the municipal water supply, electric power supply, and gas supply) and the internal equipment systems (e.g., electric power system, HVAC system, water supply system, and gas system). In addition to these physical aspects, the healthcare facility operations also require organizational and social efforts. Healthcare organizations, including medical care departments, facility management department, asset management, department, and administrative department, operate numerous facilities serving core business relating to medical care, research, laboratories, and education (102). Social units refer to the government sector, fire service, police department, and social media that provide rescue services and resources for the healthcare facilities to deal with emergency events (83). All these dimensions are not isolated but highly interconnected and mutually interdependent (101, 103, 104). For example, water supply systems require an electric power supply to maintain their normal operations, whereas the electric power system needs water resource for power delivery. Thus, modeling and analyzing the interdependent system structure of healthcare facilities is a critical step for disturbance scenario analysis. Given the interdependencies, the cascading failures occur across the systems when the disaster event happens (80, 104, 105). Specifically, one sub-system's failure or function loss may lead to knock-on consequences in others and eventual collapse of

the entire system. These cascading failures will be more serious under multiple disturbances. Thus, a full understanding of the propagation of cascade impact and synergic effect in the healthcare facility systems is necessary.

Resilience Assessment

"Measurement" is needed to identify what needs to be improved (106). Resilience assessment plays a decisive role in determining the strategies for resilient healthcare facilities development (107–109). Given this significant role, most previous HFR studies have focused on quantifying or assessing resilience. This section categorizes and reviews the existing resilience assessment methods for healthcare facilities. They are broadly grouped into three types: indicator-based, function-based, and structure-based approaches.

In terms of the indicator-based approaches, most studies proposed a generic framework for HFR assessment, which integrates several dimensions with a set of resilience measures (110). The critical steps for these approaches commonly include selecting and categorizing resilience indicators, weighing each indicator's importance, scoring the indicators, and calculating the final resilience results. For example, Bruneau et al. proposed a general framework to evaluate the seismic resilience of any physical and organizational systems (83). This framework quantifies resilience with four properties: robustness, redundancy, resourcefulness, and rapidity (83). Various studies have been implemented to quantify resilience from different perspectives to support decision-making. For example, Cimellaro et al. (111) in 2018 used a questionnaire and factor analysis to identify three resilience factors, including cooperation and training management, resources and equipment capability, and structural/organizational operating procedures. A linear combination of the three factors was eventually used to represent HFR. In sum, the indicator-based approaches capture the characteristics of multiple dimensions for HFR, and implementing these approaches is easy. However, most selected resilience indicators in the indicator-based approaches are static and cannot measure HFR in a dynamic way. The resilience capacities of healthcare facilities are process-based, which are reflected by the healthcare facilities' dynamic responses to disruptions.

The function-based approaches provide a quantitative and direct means to evaluate HFR by using the performance curve describing the functionality of healthcare facilities. Collected from the time-dependent performance curve, several macro-level indicators were used to determine dynamic resilience, such as lost functionality, downtime, and recovery time. For example, Cimellaro et al. (3) in 2011 defined the disaster resilience of a hospital as the product of technical and organizational resilience. Patient waiting time was used to measure organizational resilience. The number of untreated patients vs. the total number of patients requiring treatment, that is, healthy population loss, was used to measure technology resilience. One challenge with these approaches is that healthcare facilities' critical functionality/performance in scenario time is difficult to define (103). Common sense and previous studies indicated that the functionality of healthcare facilities can be defined in terms of quality service. For instance, Cimellaro et al. (40) in 2010 expressed seismic resilience by the patients' waiting time for treatment as an index of service quality. More attributes, such as losses, recovery cost, and time, were further selected to measure the resilience to recover from losses generated by the earthquake (40). In the case of COVID-19, the critical functionalities of healthcare facilities are to hospitalize all infected persons and continue to provide normal care for non-COVID-19 patients. Accordingly, the number of intensive care beds available and the available personal protection equipment/resources are specifically used to quantify resilience of the healthcare facilities (103). Thus, the definition of system functionality and corresponding resilience indicators will be changed according to the facing disasters. Therefore, the function-based approach can dynamically determine the resilience by comparing the macro-level functionality/performance of healthcare facilities before and after disruptions in time scenarios. However, these approaches did not take the healthcare facilities' micro-level system structures and behaviors into consideration. Consequently, it is difficult to dig out the vulnerable and critical components of the healthcare facilities and develop the targeted resilience enhancement strategies.

The structure-based approaches considered the system structures and their impact on resilience in healthcare facilities (101). The healthcare facilities' response to disturbances can be represented by modeling the system structures at the component level and then simulating the cascade failures at the system level. Several indicators from the simulation model can be used to measure the resilience level, such as many waiting patients and admission rates (6, 85). Depending on whether the behaviors of decision-makers are modeled, the present study characterizes structure-based approaches into two types: agent-based approaches and network-based approaches. Agent-based models are often used to simulate the actions and interactions of agents (112, 113). In 2001, Taboada et al. (113) modeled a hospital emergency department using a proxy-based approach, in which the changes in patient waiting time were shown under different patient arrival rates and different types and numbers of ED staff. As for the network-based approach, nodes are used to represent critical components of the system, and the relationships between nodes are represented by links (112). According to whether modeling the practical flow within systems, network-based methods can be divided into topology-based methods and flow-based methods (41). For example, Akcali et al. (114) in 2006 established a network flow model to optimize the bed capacity in a hospital under the premise of minimum cost. Arboleda et al. (101) presented a network flows model to assess the vulnerability of a healthcare facility during disaster events, considering the flow of patients within the facility, the interactions between the facility's different service areas, and the external lifeline services. In sum, the structure-based approaches capture the system's topological features and even simulate the participants' behaviors on these topological structures using agent-based technologies. The resilience mechanism can be explored by simulating the interactions between system structures, participants' behaviors, and disasters. Thus, effective strategies on resilience enhancement can be simulated in these

structure-based models, and the optimal resilience enhancement strategies would then be selected. However, concerning the accessibility of data for modeling and simulation, the structure-based approaches, particularly the agent-based methods and the flow-based methods, are difficult to access the required data. This limitation is serious in the healthcare sectors. The most complex data sets, such as the human behavior variables and the facilities' operational data, are difficult to obtain because of privacy and security issues (112).

Resilience Enhancement

The resilience enhancement of healthcare facilities is a sophisticated and systematic process, for which the type and severity of disturbances, the stage of the disturbance, the healthcare facilities conditions as well as the specific country context should be fully considered (12, 110). Generally, resilience enhancement strategies are provided later after resilience assessments. For this, we directly distilled the resilience strategies from existing research results. The following section will depict these resilience strategies at different stages of the response cycle, in which macro level (healthcare systems) and micro level (single healthcare facility) were both involved. Moreover, some resilience strategies could be conducted across stages. Here, we map specific strategies to particular stages of disaster response in order to highlight their critical relevance in these stages.

Stage 1: Preparedness and Response Planning

Resilience to acute disturbances is enhanced by adequate preparedness (46, 110). The preparedness stage relates to reducing the vulnerability of the healthcare facilities to various disturbances (46). At this stage, general preparation for any disturbances includes response planning for possible threats, resourcing those plans and holding scenario drills as planned (46). It's important to note that healthcare facilities vary widely in the degree to which they prepared for the range of possible disturbances (110). The degree of preparedness will be determined by the frequency and severity of the possible risks. Threats with high probability or high impacts should be given priority in preparedness and response planning. However, building too much preparedness for a specific disaster might increase the healthcare facilities' vulnerability to other unanticipated threats due to limited workforce and resource (12). Thus, anticipating possible disturbances and ensuring sufficient resource with adequate distribution are critical element of preparedness.

Learning from previous studies, the micro-level preparedness in single healthcare facility is summarized as the following areas: assessing the healthcare facility's structural and non-structural vulnerabilities, mapping the intensity and probability of possible threats, setting emergency plan and protocols, preparing emergency teams and assigning of responsibilities, training for emergency response procedures, and ensuring human and physical resources sufficient with appropriate level and distribution, etc. (15, 21, 46, 110, 115). The macro-level preparedness mainly relates to how well a country/region prepares for future disturbances affecting its healthcare system (12). Examples of preparedness and response planning have been specified as critical for resilience, including establishing strong leadership and accountability of government agencies for emergency response, developing coordination channels and data-sharing mechanisms across government and key stakeholders, and ensuring sufficient healthcare system resources (healthcare related resource and critical infrastructure support) and mobilizing all available resources across regions for deployment in future threats, etc. (66, 72, 74, 92). Clearly, healthcare system preparedness provides communication channels and governance mechanism for information sharing and resource support across healthcare sectors, different levels of government and the other social sectors (i.e., media, community committees and infrastructure service) in the case of emergency crisis (12). It is also noted that preparedness in single healthcare facility provides a backbone for developing and implementing national/regional preparedness and response plans (116). Specifically, single healthcare facility provides front-line data including vulnerability risks, resource requirements and service capacity, etc. (117). These data underpin effective decision-makings for developing national/regional preparedness and response plans, which includes anticipate external threats and identify internal vulnerabilities of healthcare system, clarify existing gaps between service supply and demands at national/regional level, and determine the appropriate level and distribution of resources across healthcare system (67). In addition, single healthcare facility is at the core position for supporting the implementation of national/regional plans and ensuring the continuous service delivery in response to threats (66).

Stage 2: Disturbance Onset and Alarm

The focus of this phase is on early identification of the onset and type of the disturbance (12). Clearly, the earlier that the disturbance is noticed, the faster and more effective the response actions can be. An effective surveillance and early warning system would be a powerful tool at both macro level and micro level (74, 90). Take the epidemic threats as examples, surveillance applications include detecting the abnormal increase of the case, monitoring and describing the magnitude and patterns of infectious disease, predicting epidemic trends, and discovering the emerging infectious disease (118). Then, early warning releases the signals to relevant institutions and personal for further control actions. Critically, effective surveillance and early warning system builds primarily on active data collection and information-sharing mechanisms (71, 74). Particularly, as the basic data resources, the hospitals, clinics and community care centers should take the responsibility of collecting reliable data and reporting to relevant sectors in time (67). In view of healthcare systems, it is suggested to expand the data scope and build trans-city or even transnational information monitoring systems to achieve large-scale communication and information sharing (74).

Stage 3: Disturbance Impact and Management

This stage places greater emphasis on the ability to absorb the impact of initial damage, minimize adverse consequences and ensure the continuous service delivery (98). Generally,

threats will disrupt the balance between supply and demand of healthcare service. And the shortage of health professionals and resources is serious. Experience from previous crises, increasing service capacity and adopting alternative and flexible approaches to ensure continuous healthcare delivery are strong need for strengthening resilience when healthcare facilities were shocked by threats (12). A series of specific response strategies for single healthcare facility were explored from previous studies, including triaging patients and treating them according to their urgency level, giving priority to maintaining healthcare service delivery, shifting operation activities to lower-cost settings, activating the backup resources (i.e., health professionals, medical resource, lifeline service) for increasing service capacity or preventing service disruptions (6, 8, 80, 110). The response actions of healthcare system will promote absorption and adaption abilities at strategic level. Effective information systems are critical for decision-making across healthcare system (74). For example, based on the flow of data and information across healthcare system sectors, decision-makers can precisely match the demands of healthcare and resources with available supply in view of fast response and transfer cost (78, 79, 85). It is noted that these resource sharing and coordination activities should be underpinned by emergency legislation at national/regional level (57). Additionally, transparent communication to the public, and creation of public trust and support are also crucial in response to emergencies (12).

Stage 4: Recovery and Learning

In this stage, the focus is on taking a series of adjustments to better recover from the impact of the disturbance and return to some kind of now normality (12). The post-shock context has to deal with several legacy issues, such as lost estimation, recovery decision-makings, and rebalance of the demand and supply, etc. (6, 119). For the micro-level single healthcare facility, several studies proposed specific strategies for recovery decision-makings. For instance, a decision support platform was developed for determining the priority of the damaged components and allocating recovery resources in consideration of both recovery time and cost (7, 57, 84). Ouyang et al. proposed that developing efficient communication channels and coordination mechanisms for rapid recovery response is necessary (93). In addition, other strategic legacy issues have to be done by macro-level healthcare systems. For example, scheduling recovery resources across regions or sectors and the long-term of physical and psychological treatment after shocks are great challenges (72, 74). Critically, all these decision-makings for recognizing legacy aspects and figuring out operable recovery strategies rely heavily on data collection (e.g., loss data, repair time, and required amount for recovery resources) and data analysis methods. Furthermore, learning from success and failures and adaptation to future is vital for building resilience (92). Several learning strategies could be noted for healthcare facilities, such as developing organizational learning culture and developing mechanisms to conduct feedback analysis and experience summary (46). In essence, most resilience strategies across the disaster response stages were summarized through learning from past experience.

Knowledge Gaps and Future Research

Reviewing the articles relating to HFR in 2000–2020, this study identifies the areas that are still requiring further studies. As **Figure 8** shows, these areas are summarized into the knowledge gaps of HFR and set the directions for future research.

The first knowledge gap is related to understanding and monitoring the risks for uncertain adverse events. The resilience concept emphasizes the resistant capacity of the system to understand and prevent any possible hazards (including emerging risks) (98). In terms of the functionality of healthcare facilities, monitoring the risks of public health and the loopholes of the healthcare systems are essential for the healthcare facilities' disaster prevention (67). The traditional monitoring systems usually collected public health data from clinical cases, which are labor-intensive and time-consuming (120–123). This method is inefficient for dealing with the emerging risks, particularly the epidemics with a fast spread and long incubation period (103). Taking COVID-19 for example, in some countries without powerful healthcare support and warning mechanisms, an average delay of 29 days was observed from the onset of symptoms to the detection of the epidemic outbreak (124). This delay finally resulted in the widespread COVID-19 and huge pressure on healthcare systems. Thus, studying the hazard monitoring system for healthcare facilities is urgent. Specifically, monitoring the data of climate change (e.g., the rising temperature and possible floods) and exploring their impact on public health can be noted for the early identification and monitoring of public health events (56). Furthermore, given that the clues of risks are probably hiding in the public, how to use the data from social media for monitor the public's reactions is also worth further research, in which collection methods and data cleaning technologies are critical points.

The second knowledge gap is the modeling and simulation of system interdependency. A range of recent HFR studies discussed the impact of disturbances on healthcare facilities (14, 43, 80), but few studies can use the "structure-based" method to quantify the resilience level of healthcare facilities (112). The main reason for this limitation is that existing studies do not fully support modeling and simulation of system interdependency and cascading effects for healthcare facilities (112). In terms of system interdependence, the operational healthcare facility and its emergency management heavily depend on external lifeline services, internal equipment systems, healthcare organizations, and social units (80, 125). All these dimensions are highly interconnected and mutually interdependent. In disasters, the performance deterioration of healthcare facilities can be easily amplified because of interdependencies. Thus, for HFR research, future research would characterize the structure of complex healthcare facility systems and identify approaches to simulate this interdependent system.

The third knowledge gap is related to considering the cascading effects of healthcare facilities. How disturbances cascade through the interdependent systems has to be assessed to estimate the performance deterioration and mitigate the consequences of failures (125). Some studies proposed the methods of revealing cascade failures for interdependent critical infrastructures. For example, Utne et al. developed

a cascade diagram to represent the cascading failures across the interdependent critical infrastructures under the accident scenario (126). Lam and Tai integrated network and fuzzy set theory to reveal the cascade effect from a disruption (127). Ouyang reviewed the approaches of modeling interdependent critical infrastructure systems, including empirical approaches, agent-based approaches, and network-based approaches (112). Those studies focused on the general essential infrastructure systems, such as the power grid, telecommunications, transportation, and water supply systems. However, in-depth research on modeling healthcare facility systems is still lacking. Furthermore, these proposed modeling methods for general infrastructure systems can also provide directions for HFR studies in the future.

The fourth knowledge gap is concerning the data collection for HFR modeling and simulation. All proposed resilience assessment approaches require a lot of relevant data, such as the healthcare facilities' system structures, organizational structures, operational data, emergency procedures, performance data, experts' experience, and historical events' data (112, 128). To collect these data is generally difficult because of a series of reasons. For example, much historical data on previous disturbances in healthcare facilities are incomplete and imprecise because of the backward information recording and preservation methods or awareness (129, 130). This limitation directly blocked the use of function-based approaches for empirical resilience assessment and data basis to validate other modeling and simulation methods (112). Furthermore, the healthcare facilities' operational data and their performance metrics are usually confidential because of safety issues or commercial secrets. Despite scholars and practitioners appealed to develop the data collection mechanism for events data in healthcare facilities, data collection or accidents reports for HFR studies have no standard. Thus, developing a unified database for monitoring and collecting the events data in healthcare facilities is essential. The following data standards and data analysis methods can be further researched for HFR studies.

The fifth knowledge gap is related to integration and co-simulation for HFR assessment. The previous review of resilience assessment approaches depicts that each approach has advantages and disadvantages. Function-based approaches can dynamically and directly reflect resilience capacities by the changing macro-level functionality/performance of healthcare facilities (40, 81). However, they fail to identify the critical components within healthcare facility systems that can significantly impact resilience because they did not consider the micro-level system structures, interdependences, and response behaviors (6, 128). Accordingly, the structure-based approaches only used topological indicators to represent resilience in a static way, which could not fully reveal resilience's "process-based" characteristics in a time scenario. To develop the strong points and avoid the weak points for HFR assessment studies, an open modeling framework to capture the macro-level performance indicators and the micro-level topological indicators is more desired for practical applications. This framework will involve integrating modeling and simulation methods for HFR, and specifically exploring the relationship between the micro-level topological indicators and the macro-level performance indicators in a mathematical way is necessary.

The sixth knowledge gap has to do with proactive adaptive management of healthcare facilities. Most existing studies give more efforts to existing function recovery, but little attention is devoted to recognizing the healthcare facilities as an adaptive system (92). After the disaster is completely gone, the system of healthcare facilities had been re-stabilized. In most cases, this stable state is different from the stable state before the disaster. This is due to the impact of disasters and measures implemented to ensure the functioning of healthcare facilities (12). Exploring differences between these two steady-states and their causes will be meaningful for discovering the pathways of strengthening future resilience in a system view (12). Additionally, tightly linking the recovery and learning experience to preparedness is crucial although often neglected once the function is recovered (12). Strengthening the resilience of healthcare facilities in an adaptive view is not only for improving the current system but is also better for response to future threats scenarios.

CONCLUSION

Healthcare facilities are one of the most important and complicated critical facilities in any region and country. During disasters (e.g., earthquake, flood, and epidemic), their role is even critical for rapid and effective response to casualties, injuries, or infected patients. Thus, the resilience of healthcare facilities has gained much attention in recent studies. This scientometric review aims to detect the status quo and future trends of healthcare facility resilience research. After directional search and exclusion, 374 articles between 2000 and 2020, which were gathered from the WoS core collection database, MEDLINE database and Scopus database, were analyzed to explore and visualize the current status and future trends of healthcare facility resilience research.

In terms of the temporal distribution, research on HFR has experienced three stages: preliminary exploration period (2000–2007), slow development period (2008–2014), and rapid growth period (2015–2020). Most HFR studies originated from the USA, UK, Australia, Italy, and China concerning spatial distribution. Furthermore, the institutions that conduct HFR research are relatively scattered. Regarding the subject categories in co-occurrence analysis, engineering and public and environmental and occupational health were two major research subjects. Given the keywords, "resilience," "hospital," "disaster," "health care," and "healthcare facility" had the most frequency.

According to the literature co-citation networks, seven co-citation clusters were detected. This study classified them into four knowledge domains based on their contents: climate change impact, strengthening resilience in response to war and epidemic, HFR assessment, and information system applications. Furthermore, the timeline view of literature reflected the evolution of each domain.

Based on the aforementioned scientometric analysis, a knowledge map for HFR was put forward, in which the critical research contents, current knowledge gaps, and future

research work were discussed. The critical research parts of HFR, including disturbance scenario analysis, resilience assessment, and resilience enhancement, were discussed in detail. Furthermore, knowledge gaps were identified in the areas of monitoring risk, modeling system interdependence, considering cascading effects, concerning data collection, HFR assessment barriers, and healthcare system resilience. Accordingly, the future research agenda were proposed: (1) studying the hazards monitoring system for public health based on climate change data and social media's reactions, (2) characterizing the structure of complex healthcare facility systems and exploring approaches to simulate this interdependent system, (3) modeling the cascading effects in healthcare facilities for estimating the performance deterioration and mitigating the consequences of failures, (4) developing a unified database for monitoring and collecting the standard events data for HFR research, (5) integrating and co-simulating the HFR assessment approaches for considering the micro-level topological indicators and the macro-level performance indicators, and (6) implementing proactive adaptive management of healthcare facilities.

This study provides an in-depth review of the status quo, knowledge gaps, and future research directions for researchers and practitioners in the HFR field. The proposed knowledge map of HFR is particularly useful for researchers to detect hot topics and find future research directions. Subsequently, the knowledge gaps will be filled, and the body of HFR knowledge will be extended.

AUTHOR CONTRIBUTIONS

LL conceptualized the research paper and contributed to manuscript writing. SL, JY, EW, and JS contributed to drafting the paper, data gathering, manuscript writing, data analysis and interpretation, and critical editing. All authors contributed to the article and approved the submitted version.

FUNDING

This research was supported by the National Natural Science Foundation of China (Grant Number: NSFC-71901120 and - 72072031), and Humanities and Social Science Youth Foundation, Ministry of Education of the People's Republic of China (Grant Number: 19YJCZH080).

REFERENCES

1. Tepper F. *Sendai Framework for Disaster Risk Reduction 2015-2030*. (2015). Available online at: http://www.cma.gov.cn/en2014/20150311/20151010/2015101002/201510/P020151012525690375817.pdf (accessed August 18, 2021).
2. Beck U. From industrial society to the risk society: questions of survival, social structure and ecological enlightenment. *Theory Cult Soc.* (1992) 9:97–123. doi: 10.1177/026327692009001006
3. Cimellaro GP, Reinhorn AM, Bruneau M. Performance-based metamodel for healthcare facilities. *Earthq Eng Struct Dyn.* (2011) 40:1197–217. doi: 10.1002/eqe.1084
4. Janius R, Abdan K, Zulkaflli ZA. Development of a disaster action plan for hospitals in Malaysia pertaining to critical engineering infrastructure risk analysis. *Int J Disaster Risk Reduct.* (2017) 21:168–75. doi: 10.1016/j.ijdrr.2016.12.002
5. Achour N, Price ADF. Resilience strategies of healthcare facilities: present and future. *Int J Disaster Resil Built Environ.* (2010) 1:264–76. doi: 10.1108/17595901011080869
6. Khanmohammadi S, Farahmand H, Kashani H. A system dynamics approach to the seismic resilience enhancement of hospitals. *Int J Disaster Risk Reduct.* (2018) 31:220–33. doi: 10.1016/j.ijdrr.2018.05.006
7. Her M. Repurposing and reshaping of hospitals during the COVID-19 outbreak in South Korea. *One Health.* (2020) 10:3. doi: 10.1016/j.onehlt.2020.100137
8. Cimellaro GP, Malavisi M, Mahin S. Using discrete event simulation models to evaluate resilience of an emergency department. *J Earthq Eng.* (2016) 21:203–26. doi: 10.1080/13632469.2016.1172373
9. Schulze SS, Fischer EC, Hamideh S, Mahmoud H. Wildfire impacts on schools and hospitals following the 2018 California Camp Fire. *Nat Hazards.* (2020) 104:901–25. doi: 10.1007/s11069-020-04197-0
10. Kirsch TD, Mitrani-Reiser J, Bissell R, Sauer LM, Mahoney M, Holmes WT, et al. Impact on hospital functions following the 2010 Chilean earthquake. *Disaster Med Public Health Prep.* (2010) 4:122–8. doi: 10.1001/dmphp.4.2.122
11. Jouffroy R, Puidupin A, Carli P, Vivien B. Organization of care from the field to the hospital (White Plan). *Bull Acad Natl Med.* (2016) 200:729–46. doi: 10.1016/S0001-4079(19)30698-3
12. Thomas S, Sagan A, Larkin J, Cylus J, Figueras J, Karanikolos M. *Strengthening Health Systems Resilience: Key Concepts and Strategies*. (2020). Available online at: https://europepmc.org/article/med/32716618 (accessed September 19, 2021).
13. Hugelius K, Becker J, Adolfsson A. Five challenges when managing mass casualty or disaster situations: a review study. *Int J Environ Res Public Health.* (2020) 17:13. doi: 10.3390/ijerph17093068
14. Curtis S, Fair A, Wistow J, Val DV, Oven K. Impact of extreme weather events and climate change for health and social care systems. *Environ Health.* (2017) 16:23–32. doi: 10.1186/s12940-017-0324-3
15. Zhong S, Clark M, Hou X-Y, Zang Y, FitzGerald G. Validation of a framework for measuring hospital disaster resilience using factor analysis. *Int J Environ Res Public Health.* (2014) 11:6335–53. doi: 10.3390/ijerph110606335
16. Cui C, Liu Y, Hope A, Wang J. Review of studies on the public–private partnerships (PPP) for infrastructure projects. *Int J Proj Manag.* (2018) 36:773–94. doi: 10.1016/j.ijproman.2018.03.004
17. Koks EE, Rozenberg J, Zorn C, Tariverdi M, Vousdoukas M, Fraser SA, et al. A global multi-hazard risk analysis of road and railway infrastructure assets. *Nat Commun.* (2019) 10:11. doi: 10.1038/s41467-019-10442-3
18. Haldane V, Zhang Z, Abbas RF, Dodd W, Lau LL, Kidd MR, et al. National primary care responses to COVID-19: a rapid review of the literature. *BMJ Open.* (2020) 10:10. doi: 10.1136/bmjopen-2020-041622
19. Fallah-Aliabadi S, Ostadtaghizadeh A, Ardalan A, Fatemi F, Khazai B, Mirjalili MR. Towards developing a model for the evaluation of hospital disaster resilience: a systematic review. *BMC Health Serv Res.* (2020) 20:11. doi: 10.1186/s12913-020-4915-2
20. Gajic G, Djurdjevic L, Kostic O, Jaric S, Mitrovic M, Pavlovic P. Ecological potential of plants for phytoremediation and ecorestoration of fly ash deposits and mine wastes. *Front Environ Sci.* (2018) 6:24. doi: 10.3389/fenvs.2018.00124
21. Zhong S, Clark M, Hou X-Y, Zang Y-L, Fitzgerald G. Development of hospital disaster resilience: conceptual framework and potential measurement. *Emerg Med J.* (2014) 31:930–8. doi: 10.1136/emermed-2012-202282
22. Son C, Sasangohar F, Rao AH, Larsen EP, Neville T. Resilient performance of emergency department: patterns, models and strategies. *Saf Sci.* (2019) 120:362–73. doi: 10.1016/j.ssci.2019.07.010
23. Borner K, Chen CM, Boyack KW. Visualizing knowledge domains. *Annu Rev Inform Sci Technol.* (2003) 37:179–255. doi: 10.1002/aris.1440370106

24. Zhao X, Zuo J, Wu G, Huang C. A bibliometric review of green building research 2000-2016. *Archit Sci Rev.* (2019) 62:74–88. doi: 10.1080/00038628.2018.1485548
25. van Leeuwen T. The application of bibliometric analyses in the evaluation of social science research. Who benefits from it, and why it is still feasible. *Scientometrics.* (2006) 66:133–54. doi: 10.1007/s11192-006-0010-7
26. Chen C. Science mapping: a systematic review of the literature. *J Data Inf Sci.* (2017) 2:1–40. doi: 10.1515/jdis-2017-0006
27. Chen C. *CiteSpace-Visualizing Patterns and Trends in Scientific Literature*. (2003). Available online at: http://cluster.cis.drexel.edu/~cchen/citespace/ (accessed September 19, 2021).
28. Cerchione R, Esposito E. A systematic review of supply chain knowledge management research: state of the art and research opportunities. *Int J Prod Econ.* (2016) 182:276–92. doi: 10.1016/j.ijpe.2016.09.006
29. Hu W, Dong J, Hwang B-g, Ren R, Chen Z. A scientometrics review on city logistics literature: research trends, advanced theory and practice. *Sustainability.* (2019) 11:27. doi: 10.3390/su11102724
30. Giorgi G, Lecca LI, Alessio F, Finstad GL, Bondanini G, Lulli LG, et al. COVID-19-related mental health effects in the workplace: a narrative review. *Int J Environ Res Public Health.* (2020) 17:22. doi: 10.3390/ijerph17217857
31. Hasani A, Khosrojerdi A. Robust global supply chain network design under disruption and uncertainty considering resilience strategies: a parallel memetic algorithm for a real-life case study. *Transp Res Pt eLogist Transp Rev.* (2016) 87:20–52. doi: 10.1016/j.tre.2015.12.009
32. Yin KY, Divakar P, Wegst UGK. Freeze-casting porous chitosan ureteral stents for improved drainage. *Acta Biomater.* (2019) 84:231–41. doi: 10.1016/j.actbio.2018.11.005
33. Caswell N, Kuru K, Ansell D, Jones MJ, Watkinson BJ, Leather P, et al. Patient engagement in medical device design: refining the essential attributes of a wearable, pre-void, ultrasound alarm for nocturnal enuresis. *Pharm Med.* (2020) 34:39–48. doi: 10.1007/s40290-019-00324-w
34. Chen C, Dubin R, Kim MC. Emerging trends and new developments in regenerative medicine: a scientometric update (2000 - 2014). *Expert Opin Biol Ther.* (2014) 14:1295–317. doi: 10.1517/14712598.2014.920813
35. Wang L, Xue X, Zhang Y, Luo X. Exploring the emerging evolution trends of urban resilience research by scientometric analysis. *Int J Environ Res Public Health.* (2018) 15:2181–210. doi: 10.3390/ijerph15102181
36. Zhao X. A scientometric review of global BIM research: analysis and visualization. *Autom Constr.* (2017) 80:37–47. doi: 10.1016/j.autcon.2017.04.002
37. Zhu S, Li D, Feng H, Gu T, Hewage K, Sadiq R. Smart city and resilient city: differences and connections. *Wiley Interdiscip Rev Data Mining Knowl Discov.* (2020) 10:19. doi: 10.1002/widm.1388
38. Chen C, Hu Z, Liu S, Tseng H. Emerging trends in regenerative medicine: a scientometric analysis in CiteSpace. *Expert Opin Biol Ther.* (2012) 12:593–608. doi: 10.1517/14712598.2012.674507
39. Sharifi A. Urban resilience assessment: mapping knowledge structure and trends. *Sustainability.* (2020) 12:5918. doi: 10.3390/su12155918
40. Cimellaro GP, Reinhorn AM, Bruneau M. Seismic resilience of a hospital system. *Struct Infrastruct Eng.* (2010) 6:127–44. doi: 10.1080/15732470802663847
41. Lomas KJ, Giridharan R, Short CA, Fair AJ. Resilience of "Nightingale" hospital wards in a changing climate. *Build Serv Eng Res Technol.* (2012) 33:81–103. doi: 10.1177/0143624411432012
42. Short CA, Lomas KJ, Giridharan R, Fair AJ. Building resilience to overheating into 1960's UK hospital buildings within the constraint of the national carbon reduction target: adaptive strategies. *Build Environ.* (2012) 55:73–95. doi: 10.1016/j.buildenv.2012.02.031
43. Lomas KJ, Giridharan R. Thermal comfort standards, measured internal temperatures and thermal resilience to climate change of free-running buildings: a case-study of hospital wards. *Build Environ.* (2012) 55:57–72. doi: 10.1016/j.buildenv.2011.12.006
44. Hajat S, O'Connor M, Kosatsky T. Health effects of hot weather: from awareness of risk factors to effective health protection. *Lancet.* (2010) 375:856–63. doi: 10.1016/S0140-6736(09)61711-6
45. Nitschke M, Tucker GR, Hansen AL, Williams S, Zhang Y, Bi P. Impact of two recent extreme heat episodes on morbidity and mortality in Adelaide, South Australia: a case-series analysis. *Environ Health.* (2011) 10:9. doi: 10.1186/1476-069X-10-42
46. Chand AM, Loosemore M. Hospital learning from extreme weather events: using causal loop diagrams. *Build Res Informat.* (2016) 44:875–88. doi: 10.1080/09613218.2016.1097805
47. Codjoe SNA, Gough KV, Wilby RL, Kasei R, Yankson PWK, Amankwaa EF, et al. Impact of extreme weather conditions on healthcare provision in urban Ghana. *Soc Sci Med.* (2020) 258:12. doi: 10.1016/j.socscimed.2020.113072
48. Corvalan C, Villalobos Prats E, Sena A, Campbell-Lendrum D, Karliner J, Risso A, et al. Towards climate resilient and environmentally sustainable health care facilities. *Int J Environ Res Public Health.* (2020) 17:18. doi: 10.3390/ijerph17238849
49. Bean R, Snow S, Glencross M, Viller S, Horrocks N. Keeping the power on to home medical devices. *PLoS ONE.* (2020) 15:e0235068. doi: 10.1371/journal.pone.0235068
50. Hutton NS, Allen MJ. Challenges in upgrading emergency power in florida nursing homes following hurricane irma. *Weather Clim Soc.* (2020) 12:805–14. doi: 10.1175/WCAS-D-19-0064.1
51. Hiete M, Merz M, Schultmann F. Scenario-based impact analysis of a power outage on healthcare facilities in Germany. *Int J Disaster Resilience Built Environ.* (2011) 2:222–44. doi: 10.1108/17595901111167105
52. Kyriakarakos G, Dounis A. Intelligent management of distributed energy resources for increased resilience and environmental sustainability of hospitals. *Sustainability.* (2020) 12:4. doi: 10.3390/su12187379
53. Lagrange A, de Simón-Martín M, González-Martínez A, Bracco S, Rosales-Asensio E. Sustainable microgrids with energy storage as a means to increase power resilience in critical facilities: an application to a hospital. *Int J Electr Power Energy Syst.* (2020) 119:105865. doi: 10.1016/j.ijepes.2020.105865
54. Costello A, Abbas M, Allen A, Ball S, Bell S, Bellamy R, et al. Managing the health effects of climate change. *Lancet.* (2009) 373:1693–733. doi: 10.1016/S0140-6736(09)60935-1
55. Giridharan R, Lomas KJ, Short CA, Fair AJ. Performance of hospital spaces in summer: a case study of a 'Nucleus'-type hospital in the UK Midlands. *Energy Build.* (2013) 66:315–28. doi: 10.1016/j.enbuild.2013.07.001
56. Li M, Gu S, Bi P, Yang J, Liu Q. Heat waves and morbidity: current knowledge and further direction-a comprehensive literature review. *Int J Environ Res Public Health.* (2015) 12:5256–83. doi: 10.3390/ijerph120505256
57. Watts N, Adger WN, Agnolucci P, Blackstock A, Byass P, Cai WJ, et al. Health and climate change: policy responses to protect public health. *Lancet.* (2015) 386:1861–914. doi: 10.1016/S0140-6736(15)60854-6
58. United Nations. *Sendai Framework for Disaster Risk Reduction 2015 - 2030.* (2015). Available online at: http://www.cma.gov.cn/en2014/20150311/20151010/2015101002/201510/P020151012525690375817.pdf (accessed October 2, 2021).
59. Runkle J, Svendsen ER, Hamann M, Kwok RK, Pearce J. Population health adaptation approaches to the increasing severity and frequency of weather-related disasters resulting from our changing climate: a literature review and application to Charleston, South Carolina. *Curr Environ Health Rep.* (2018) 5:439–52. doi: 10.1007/s40572-018-0223-y
60. Mayer B. A review of the literature on community resilience and disaster recovery. *Curr Environ Health Rep.* (2019) 6:167–73. doi: 10.1007/s40572-019-00239-3
61. Kendrovski V, Schmoll O. Priorities for protecting health from climate change in the WHO European Region: recent regional activities. *Bundesgesundheitsblatt Gesundheitsforschung Gesundheitsschutz.* (2019) 62:537–45. doi: 10.1007/s00103-019-02943-9
62. Fouad FM, Sparrow A, Tarakji A, Alameddine M, El-Jardali F, Coutts AP, et al. Health workers and the weaponisation of health care in Syria: a preliminary inquiry for the lancet – American University of Beirut Commission on Syria. *Lancet.* (2017) 390:2516–26. doi: 10.1016/S0140-6736(17)30741-9
63. Dewachi O, Skelton M, Nguyen V-K, Fouad FM, Sitta GA, Maasri Z, et al. Changing therapeutic geographies of the Iraqi and Syrian wars. *Lancet.* (2014) 383:449–57. doi: 10.1016/S0140-6736(13)62299-0
64. Tappis H, Elaraby S, Elnakib S, AlShawafi NAA, BaSaleem H, Al-Gawfi IAS, et al. Reproductive, maternal, newborn and child health service delivery during conflict in Yemen: a case study. *Confl Health.* (2020) 14:30. doi: 10.1186/s13031-020-00269-x

65. Fardousi N, Douedari Y, Howard N. Healthcare under siege: a qualitative study of health-worker responses to targeting and besiegement in Syria. *BMJ Open.* (2019) 9:12. doi: 10.1136/bmjopen-2019-029651
66. Jamal Z, Alameddine M, Diaconu K, Lough G, Witter S, Ager A, et al. Health system resilience in the face of crisis: analysing the challenges, strategies and capacities for UNRWA in Syria. *Health Policy Plan.* (2019) 35:26–35. doi: 10.1093/heapol/czz129
67. Kruk ME, Myers M, Varpilah ST, Dahn BT. What is a resilient health system? Lessons from Ebola. *Lancet.* (2015) 385:1910–2. doi: 10.1016/S0140-6736(15)60755-3
68. Cousins S. Syrian crisis: health experts say more can be done. *Lancet.* (2015) 385:931–4. doi: 10.1016/S0140-6736(15)60515-3
69. Biddle L, Wahedi K, Bozorgmehr K. Health system resilience: a literature review of empirical research. *Health Policy Plan.* (2020) 35:1084–109. doi: 10.1093/heapol/czaa032
70. Gilson L, Barasa E, Nxumalo N, Cleary S, Goudge J, Molyneux S, et al. Everyday resilience in district health systems: emerging insights from the front lines in Kenya and South Africa. *BMJ Glob Health.* (2017) 2:e000224. doi: 10.1136/bmjgh-2016-000224
71. Kieny M-P, Evans DB, Schmets G, Kadandale S. Health-system resilience: reflections on the Ebola crisis in western Africa. *Bull World Health Organ.* (2014) 92:850. doi: 10.2471/BLT.14.149278
72. Douedari Y, Howard N. Perspectives on rebuilding health system governance in opposition-controlled Syria: a qualitative study. *Int J Health Policy Manag.* (2019) 8:233–44. doi: 10.15171/ijhpm.2018.132
73. Raven J, Wurie H, Witter S. Health workers' experiences of coping with the Ebola epidemic in Sierra Leone's health system: a qualitative study. *BMC Health Serv Res.* (2018) 18:251. doi: 10.1186/s12913-018-3072-3
74. Kluge H, Martin-Moreno JM, Emiroglu N, Rodier G, Kelley E, Vujnovic M, et al. Strengthening global health security by embedding the International Health Regulations requirements into national health systems. *BMJ Glob Health.* (2018) 3 (Suppl. 1):e000656. doi: 10.1136/bmjgh-2017-000656
75. Rubenstein LS, Bittle MD. Responsibility for protection of medical workers and facilities in armed conflict. *Lancet.* (2010) 375:329–40. doi: 10.1016/S0140-6736(09)61926-7
76. Moradi S, Vasandani V, Nejat A. A review of resilience variables in the context of disasters. *J Emerg Manag.* (2019) 17:403–32. doi: 10.5055/jem.2019.0431
77. Davis CA. Understanding functionality and operability for infrastructure system resilience. *Nat Hazards Rev.* (2021) 22:6. doi: 10.1061/(ASCE)NH.1527-6996.0000431
78. Jacques CC, McIntosh J, Giovinazzi S, Kirsch TD, Wilson T, Mitrani-Reiser J. Resilience of the canterbury hospital system to the 2011 Christchurch earthquake. *Earthq Spectra.* (2014) 30:533–54. doi: 10.1193/032013EQS074M
79. Mitrani-Reiser J, Mahoney M, Holmes WT, Carlos de la Llera J, Bissell R, Kirsch T. A functional loss assessment of a hospital system in the bio-bio province. *Earthq Spectra.* (2012) 28:S473–S502. doi: 10.1193/1.4000044
80. Achour N, Miyajima M, Pascale F, Price ADF. Hospital resilience to natural hazards: classification and performance of utilities. *Disaster Prev Manag.* (2014) 23:40–52. doi: 10.1108/DPM-03-2013-0057
81. Cimellaro GP, Reinhorn AM, Bruneau M. Framework for analytical quantification of disaster resilience. *Eng Struct.* (2010) 32:3639–49. doi: 10.1016/j.engstruct.2010.08.008
82. Cimellaro GP, Marasco S, Noori AZ, Mahin SA. A first order evaluation of the capacity of a healthcare network under emergency. *Earthq Eng Eng Vib.* (2019) 18:663–77. doi: 10.1007/s11803-019-0528-3
83. Bruneau M, Chang SE, Eguchi RT, Lee GC, O'Rourke TD, Reinhorn AM, et al. A framework to quantitatively assess and enhance the seismic resilience of communities. *Earthq Spectra.* (2003) 19:733–52. doi: 10.1193/1.1623497
84. Bruneau M, Reinhorn A. Exploring the concept of seismic resilience for acute care facilities. *Earthq Spectra.* (2007) 23:41–62. doi: 10.1193/1.2431396
85. Hassan EM, Mahmoud H. An integrated socio-technical approach for post-earthquake recovery of interdependent healthcare system. *Reliab Eng Syst Saf.* (2020) 201:15. doi: 10.1016/j.ress.2020.106953
86. Ferguson WJ, Kemp K, Kost G. Using a geographic information system to enhance patient access to point-of-care diagnostics in a limited-resource setting. *Int J Health Geogr.* (2016) 15:12. doi: 10.1186/s12942-016-0037-9
87. Kost GJ, Ferguson W. Spatial care paths (TM) strengthen links in the chain of global resilience disaster caches, prediabetes, ebola virus disease, and the future of point of care. *Point Care.* (2016) 15:43–58. doi: 10.1097/POC.0000000000000080
88. Paturas J, Smith D, Smith S, Albanese J. Collective response to public health emergencies and large-scale disasters: putting hospitals at the core of community resilience. *J Bus Contin Emer Plan.* (2010) 4:286–95.
89. Bhaskar S, Bradley S, Chattu VK, Adisesh A, Nurtazina A, Kyrykbayeva S, et al. Telemedicine as the new outpatient clinic gone digital: position paper from the Pandemic Health System REsilience PROGRAM (REPROGRAM) International Consortium (Part 2). *Front Public Health.* (2020) 8:410. doi: 10.3389/fpubh.2020.00410
90. Romani G, Dal Mas F, Massaro M, Cobianchi L, Modenese M, Barcellini A, et al. Population health strategies to support hospital and intensive care unit resiliency during the COVID-19 pandemic: the italian experience. *Popul Health Manag.* (2020) 24:174–81. doi: 10.1089/pop.2020.0255
91. Haimes YY. On the definition of resilience in systems. *Risk Anal.* (2009) 29:498–501. doi: 10.1111/j.1539-6924.2009.01216.x
92. Barasa E, Mbau R, Gilson L. What is resilience and how can it be nurtured? A systematic review of empirical literature on organizational resilience. *Int J Health Policy Manag.* (2018) 7:491–503. doi: 10.15171/ijhpm.2018.06
93. The World Bank. *According to the Country Income Classification Criteria Published by the World Bank in 2021.* (2021). Available online at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups?continueFlag=a206b43e3689c50cb9affa3a7f76df8a (accessed October 2, 2021).
94. Yu P, Wen W, Ji D, Zhai C, Xie L. A framework to assess the seismic resilience of urban hospitals. *Adv Civ Eng.* (2019) 2019:1–11. doi: 10.1155/2019/7654683
95. Saurí D. *Mapping the Impacts of Recent Natural Disasters and Technological Accidents in Europe*. Copenhagen: Office for official publications of the European Communities (2003).
96. Xu Q, Fan XM, Huang RQ, Van Westen C. Landslide dams triggered by the Wenchuan Earthquake, Sichuan Province, south west China. *Bull Eng Geol Environ.* (2009) 68:373–86. doi: 10.1007/s10064-009-0214-1
97. Cui P, Chen XQ, Zhu YY, Su FH, Wei FQ, Han YS, et al. The Wenchuan Earthquake (May 12, 2008), Sichuan Province, China, and resulting geohazards. *Nat Hazards.* (2011) 56:19–36. doi: 10.1007/s11069-009-9392-1
98. Ouyang M, Duenas-Osorio L, Min X. A three-stage resilience analysis framework for urban infrastructure systems. *Struct Saf.* (2012) 36-37:23–31. doi: 10.1016/j.strusafe.2011.12.004
99. Zhao S, Liu X, Zhuo Y. Hybrid Hidden Markov Models for resilience metrics in a dynamic infrastructure system. *Reliab Eng Syst Saf.* (2017) 164:84–97. doi: 10.1016/j.ress.2017.02.009
100. Qirbi N, Ismail SA. Health system functionality in a low-income country in the midst of conflict: the case of Yemen. *Health Policy Plan.* (2017) 32:911–22. doi: 10.1093/heapol/czx031
101. Arboleda CA, Abraham DM, Richard J-PP, Lubitz R. Vulnerability assessment of health care facilities during disaster events. *J Infrastruct Syst.* (2009) 15:149–61. doi: 10.1061/(ASCE)1076-0342 (2009) 15:3(149)
102. Shirey WT, Sullivan KT, Lines B, Smithwick J. Application of lean six sigma to improve service in healthcare facilities management: a case study. *J Facility Manage Educ Res.* (2017) 1:9–18. doi: 10.22361/jfmer/78724
103. Jovanovic A, Klimek P, Renn O, Schneider R, Oien K, Brown J, et al. Assessing resilience of healthcare infrastructure exposed to COVID-19: emerging risks, resilience indicators, interdependencies and international standards. *Environ Syst Decis.* (2020) 40:252–86. doi: 10.1007/s10669-020-09779-8
104. Rinaldi SA, Peerenboom JP, Kelly TK. Identifying, understanding, and analyzing critical infrastructure interdependencies. *IEEE Control Syst Mag.* (2001) 21:11–25. doi: 10.1109/37.969131
105. Yavari S, Chang SE, Elwood KJ. Modeling post-earthquake functionality of regional health care facilities. *Earthq Spectra.* (2010) 26:869–92. doi: 10.1193/1.3460359
106. Liu HJ, Love PED, Sing MCP, Niu BZ, Zhao JF. Conceptual framework of life-cycle performance measurement: ensuring the resilience of transport infrastructure assets. *Transport Res Part D Transport Environ.* (2019) 77:615–26. doi: 10.1016/j.trd.2019.10.002

107. Davoudi S, Shaw K, Haider LJ, Quinlan AE, Peterson GD, Wilkinson C, et al. Resilience: a bridging concept or a dead end? *Plan Theory.* (2012) 13:299–333. doi: 10.1080/14649357.2012.677124
108. Sellberg MM, Wilkinson C, Peterson GD. Resilience assessment: a useful approach to navigate urban sustainability challenges. *Ecol Soc.* (2015) 20:24. doi: 10.5751/ES-07258-200143
109. Heinimann HR, Hatfield K. Infrastructure resilience assessment, management and governance–state and perspectives. In: Linkov I, Palma-Oliveira JM, editors. *Resilience and Risk*. Dordrecht: Springer (2017). p. 147–87.
110. Li X, Huang J, Zhang H. An analysis of hospital preparedness capacity for public health emergency in four regions of China: Beijing, Shandong, Guangxi, and Hainan. *BMC Public Health.* (2008) 8:11. doi: 10.1186/1471-2458-8-319
111. Cimellaro GP, Malavisi M, Mahin S. Factor analysis to evaluate hospital resilience. *ASCE ASME J Risk Uncertain Eng Syst A Civ Eng.* (2018) 4:04018002. doi: 10.1061/AJRUA6.0000952
112. Ouyang M. Review on modeling and simulation of interdependent critical infrastructure systems. *Reliab Eng Syst Saf.* (2014) 121:43–60. doi: 10.1016/j.ress.2013.06.040
113. Taboada M, Cabrera E, Iglesias ML, Epelde F, Luque E. An agent-based decision support system for hospitals emergency departments. *Procedia Comput Sci.* (2011) 4:1870–9. doi: 10.1016/j.procs.2011.04.203
114. Akcali E, Cote MJ, Lin C. A network flow approach to optimizing hospital bed capacity decisions. *Health Care Manag Sci.* (2006) 9:391–404. doi: 10.1007/s10729-006-0002-4
115. Fallah-Aliabadi S, Ostadtaghizadeh A, Ardalan A, Eskandari M, Fatemi F, Mirjalili MR, et al. Risk analysis of hospitals using GIS and HAZUS: a case study of Yazd County, Iran. *Int J Disaster Risk Reduct*. (2020) 47:13. doi: 10.1016/j.ijdrr.2020.101552
116. European Commission. *State of Health in the EU: Country Health Profiles Series*. Brussels:European Commission (2019). Available online at: https://ec.europa.eu/health/state/country_profiles_en (accessed October 2, 2021).
117. Cutter SL, Ahearn JA, Amadei B, Crawford P, Eide EA, Galloway GE, et al. Disaster resilience: a national imperative. *Environment.* (2013) 55:25–9. doi: 10.1080/00139157.2013.768076
118. Yang W. *Early Warning for Infectious Disease Outbreak: Theory and Practice*. London: Academic Press (2017).
119. Naimoli JF, Saxena S. Realizing their potential to become learning organizations to foster health system resilience: opportunities and challenges for health ministries in low- and middle-income countries. *Health Policy Plan.* (2018) 33:1083–95. doi: 10.1093/heapol/czy100
120. Gupta A, Katarya R. Social media based surveillance systems for healthcare using machine learning: a systematic review. *J Biomed Inform.* (2020) 108:13. doi: 10.1016/j.jbi.2020.103500
121. Velasco E, Agheneza T, Denecke K, Kirchner G, Eckmanns T. Social media and internet-based data in global systems for public health surveillance: a systematic review. *Milbank Q.* (2014) 92:7–33. doi: 10.1111/1468-0009.12038
122. Yan SJ, Chughtai AA, Macintyre CR. Utility and potential of rapid epidemic intelligence from internet-based sources. *Int J Infect Dis.* (2017) 63:77–87. doi: 10.1016/j.ijid.2017.07.020
123. Sharp TM, Ryff KR, Santiago GA, Margolis HS, Waterman SH. Lessons learned from dengue surveillance and research, Puerto Rico, 1899-2013. *Emerg Infect Dis.* (2019) 25:1522–30. doi: 10.3201/eid2508.190089
124. Bruckner C, Checchi F. Detection of infectious disease outbreaks in twenty-two fragile states, 2000-2010: a systematic review. *Confl Health.* (2011) 5:13. doi: 10.1186/1752-1505-5-13
125. Yusta JM, Correa GJ, Lacal-Arántegui R. Methodologies and applications for critical infrastructure protection: state-of-the-art. *Energy Policy.* (2011) 39:6100–19. doi: 10.1016/j.enpol.2011.07.010
126. Utne IB, Hokstad P, Vatn J. A method for risk modeling of interdependencies in critical infrastructures. *Reliab Eng Syst Saf.* (2011) 96:671–8. doi: 10.1016/j.ress.2010.12.006
127. Lam CY, Tai K. Modeling infrastructure interdependencies by integrating network and fuzzy set theory. *Int J Crit Infrastruct Prot.* (2018) 22:51–61. doi: 10.1016/j.ijcip.2018.05.005
128. Li Z, Li N, Cimellaro GP, Fang D. system dynamics modeling-based approach for assessing seismic resilience of hospitals: methodology and a case in China. *J Manage Eng.* (2020) 36:14. doi: 10.1061/(ASCE)ME.1943-5479.0000814
129. Sun L, Stojadinovic B, Sansavini G. Agent-based recovery model for seismic resilience evaluation of electrified communities. *Risk Anal.* (2019) 39:1597–614. doi: 10.1111/risa.13277
130. Dhulipala SLN, Flint MM. Series of semi-Markov processes to model infrastructure resilience under multihazards. *Reliab Eng Syst Saf.* (2020) 193:8. doi: 10.1016/j.ress.2019.106659

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 06 December 2021
doi: 10.3389/fpsyg.2021.783415

The Influence of the Debunker's Identity and Emotional Expression on the Sharing Behavior of Debunking Information

*Fan Chao, Xin Wang and Guang Yu**

School of Management, Harbin Institute of Technology, Harbin, China

Owing to the proliferation of rumors on social media, it is necessary to disseminate debunking information to minimize the harm caused by them. Using content analysis, sentiment analysis, and regression analysis, this study examined the mediating role of follower count in the relationship between the debunker's identity and sharing behavior, and it explored the relationship between the text sentiment of debunking information and sharing behavior based on data on the spread of three rumors that circulated extensively on social media. Using an ordinary account as a reference, we found that the mediating or suppression effect (i.e., when direct and indirect effects are significant and opposite) of follower count in the relationship between debunker's identity (celebrity, media, or government) and sharing behavior was significant. The three test identities (celebrity, media, and government) had more followers than the ordinary account, which resulted in a significant positive effect on the number of reposts. The debunker's identity did not have a positive effect on the sharing of debunking information when controlling for mediating variables. Debunking information with emotional overtones (positive or negative) was shared more widely compared with information with neutral emotions, and the dominant emotional polarity was different in the three different rumors. These findings can contribute to the generation of debunking information content, which can aid in the development of effective communication strategies and improvement in the efficiency of crisis management.

Keywords: rumor, debunking information, social media, debunker's identity, textual emotions, crisis management

OPEN ACCESS

Edited by:
Eric Carlström,
University of Gothenburg, Sweden

Reviewed by:
Lindsey A. Harvell-Bowman,
James Madison University,
United States
Cynthia Whissell,
Laurentian University, Canada

***Correspondence:**
Guang Yu
yug@hit.edu.cn

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *26 September 2021*
Accepted: *15 November 2021*
Published: *06 December 2021*

Citation:
Chao F, Wang X and Yu G (2021) The Influence of the Debunker's Identity and Emotional Expression on the Sharing Behavior of Debunking Information. Front. Psychol. 12:783415. doi: 10.3389/fpsyg.2021.783415

INTRODUCTION

The spread of rumors, especially on social media, has had a serious impact on network order and social development (Lazer et al., 2018; Allen et al., 2020). It can cause panic, lead to false accusations, and interfere with the work of emergency response agencies, posing a threat to public safety (Jung et al., 2020). Particularly, since the outbreak of COVID-19, the spread of rumors has become more concerning than the prevention and treatment of the disease itself, causing significant negative consequences (Kassam, 2020). To mitigate the potential harm caused by rumors, it is necessary to dispel them by disseminating debunked information.

Inadequate information to debunk rumors is a key impediment to damage control. For effective debunking, correct information must reach all persons who have encountered the rumors

(Wu, 2020). Rumors spread widely to drown out factual as well as retroactive information. One powerful evidence is that messages from the World Health Organization (WHO) and the US Center for Disease Control and Prevention (CDC) received only a few hundred thousand responses (retweets, likes and comments, etc.) at the height of the COVID-19 pandemic. Conversely, false information and information about conspiracy theories gained 52 million views (Mian and Khan, 2020). The amount of debunking information is always less than that passing on rumors. This means that the overall impact of debunking information is limited (Jung et al., 2020).

Further, researchers have found that most users who believe rumors do not take corrective action after reading the debunking information (Arif et al., 2017). Scholars who investigated the reactions of misinformed Twitter users after the users read debunking information found that they do not take any real action after seeing the debunking information (Wang and Zhuang, 2018). Consequently, rumors always spread faster and wider than debunking information, making it difficult for debunking information to curb the rumor spread and significantly reducing the effectiveness of debunking behavior (Vosoughi et al., 2018; Wang and Qian, 2021). It is important to investigate the behavior of sharing (referred to as *sharing behavior* hereon) debunking information; develop strategies that enable wider dissemination of debunking information; and form an effective countermeasure to curb the spread of rumors, mitigate the harm caused by them, and improve the efficiency of crisis management systems.

Five basic components of how individuals communicate with one another include *who*, *what*, through *which* channel, to *whom*, and with *what* effect (Lasswell, 1948). In the present study, from the perspective of the information publisher, the main concerns are the *who*, *what,* and *which* channel.

In the real world, people are concerned with the source of a story (McCracken, 1989). We accept statements from those we regard as experts (Hovland et al., 1953). Scholars have conducted empirical analyses of rumor development. The findings have suggested that rumors that are debunked by official sources are more likely to be arrested from continuing to spread (Andrews et al., 2016; Jung et al., 2020). Regarding the relationship between information sources and sharing behavior, Kim and Dennis (2019) found that highlighting the source of an article affects the extent to which readers trust the article, which in turn influences users' engagement with the same (e.g., read, like, comment, and share). However, to the best of our knowledge, no further research has been conducted on the relationship between the identity of debunkers and information-sharing behavior. Previous research about the effect of type of source on sharing behavior has mostly used an experimental approach, studying the intention to share rather than the actual act of sharing. Using real data from social media, the relationship between debunker identity and sharing behavior in the context of social media can be studied with better ecological validity (Burton et al., 2021).

In this manuscript, the identity of the debunker refers to the type of Weibo account—that is, ordinary, celebrity, media, and government. This study focuses on the following question: How does the debunker's identity affect the sharing behavior of information that is intended to debunk a rumor that has been spread through social media? It is clear that certain types of accounts have many followers. Accordingly, it is difficult to determine whether the behavior of reposting debunking information is influenced by the type of account or a higher number of followers.

Previous studies have confirmed the relationship between emotions and information dissemination. Messages with emotional overtones were forwarded more frequently and rapidly than neutral messages (Stieglitz and Dang-Xuan, 2013). Although negative messages spread faster than positive ones, positive messages reached larger audiences. This suggests that people prefer sharing positive content. This is known as positive bias (Ferrara and Yang, 2015). Moreover, some researchers have explored the influence of emotion on the spreading of rumors. For instance, Weeks (2015) and Martel et al. (2020) established that anger can promote belief in rumors and that emotional response increases belief in false news. This can make debunking difficult. Emotions play a significant role in the proliferation of both conventional information and rumors. However, debunking behaviors and debunking information have a specific set of characteristics that are less likely to gain attention and reposts than rumors (Arif et al., 2017; Wang and Zhuang, 2018). It is unclear whether the use of emotional language in debunking information increases the likelihood of reposting. Moreover, there are many potential problems with sentiment analysis of text data on social media. First, for data obtained from social media, pre-processing procedures such as removing deactivated words and removing account names or hashtags are usually needed at the initial stage, which do not have a strict standard; this may lead to different interpretations of the data (Burton et al., 2021). Second, the decision to use a lexical (or bag-of-words) approach or machine learning strategy in text classification may result in differences in the recognition of moral expressions in the same corpus, and classification performance may vary by context (Hoover et al., 2020). Finally, although computerized sentiment analysis allows researchers to test hypotheses on a larger dataset, it does not capture specific sentiments, such as sarcasm, which can render the final classification results biased (Stieglitz and Dang-Xuan, 2013). In view of the shortcomings of previous studies, this study first makes improvements to the sentiment analysis method to obtain more accurate sentiment classification results and then examines the relationship between text sentiment and sharing behavior in the context of social media.

Using the bootstrap method, this study examined the mediating role of follower count between three categories of social media accounts (celebrity, media, and government accounts) and the number of reposts, with the ordinary account as reference. A negative binomial regression model was used to examine the relationship between the sentiment expressed in debunking information and the number of reposts. We found that the relative mediating effect, or suppression effect of follower count, between these three types of accounts and sharing behavior was significant. The three account types had a significant positive effect on the number of reposts through the follower count. Further, after controlling for mediating variables, the

debunker's identity contributed little to the sharing of debunking information. In addition, debunking information with emotional overtones (positive or negative) was more likely to be reposted. However, the dominant emotional polarity varied in different rumor transmission contexts.

THEORETICAL BASES AND HYPOTHESES

The Relationship Between the Debunker's Identity and the Number of Reposts of the Debunking Information

The way we perceive the source shapes the way we think about subsequent information. We tend to view information from reputable sources positively and information from disreputable sources negatively; therefore, we are more likely to trust information from reputable sources (Tormala et al., 2006, 2007). Most debunking information posted by personal accounts is associated with news agencies and government organizations (Hunt et al., 2020). In addition, influential accounts on social media, such as media and celebrities, trigger more interactive behavior (Stieglitz and Dang-Xuan, 2013). Therefore, we propose the following hypothesis:

> *H1a: Debunking information posted by celebrities, media, and government accounts will receive more reposts than information in ordinary accounts.*

The Mediating Role of the Number of Followers of a Debunker

Scholars have found that compared to ordinary accounts, social media accounts that belong to celebrities, those that belong to media houses (e.g., Weibo-certified account of a newspaper, or a magazine), and those that belong to government organizations hold more reliable information (Andrews et al., 2016). Social media users, therefore, consult them because they are considered reliable and authoritative. The authority effect states that if a person is authoritative and respected, what they say and do is more likely to attract other people's attention and to be believed. The prevalence of the authority effect is due to the psychological human desire to feel safe. People tend to believe that authorities mean well. Their statements are, accordingly, mostly believable (Scherman, 1993). Hence, following authorities on social media makes individuals feel safe. It also increases their faith in the authorities and the credibility of what they say. Moreover, it increases their confidence in their own credibility. Furthermore, most people tend to seek approval from prominent figures (Yuhong et al., 2019). They tend to believe that the words and actions of those in authority are in line with social norms. Accordingly, individuals who are consistent with authorities receive approval or praise from others. Therefore, we propose the following hypothesis:

> *H1b: Celebrity, media, and government accounts will have more followers than ordinary account types.*

The number of followers a user has on social media represents the degree of homogeneity among their followers (Aral et al., 2009). This suggests that a user's followers are likely to have similar interests. Therefore, they are more likely to repost the user's content, leading to the following hypothesis:

> *H1c: There is a positive correlation between the number of followers and the number of reposts.*

On the basis of H1a, H1b, and H1c, the influence of a debunker's identity on information-sharing behavior can be divided into two premises: (1) the identity of the debunker directly affects the number of reposts, and (2) the identity of the debunker affects the number of reposts by influencing the number of followers. Thus, we propose the following hypothesis:

> *H1: Using the ordinary account type as the reference, follower count is a relative mediating variable between celebrity, media, and government-type accounts and repost counts.*

The Relationship Between Sentiment and the Number of Reposts of Debunking Information

The social contagion theory holds that individuals' emotions and behaviors can be influenced by other people's words, texts, expressions, gestures, and other messages (Kunitski et al., 2019). Users unconsciously spread positive and negative emotions through the comments they pass on to others through social networks. They trigger similar emotions and behaviors. People who use emotive language (including both positive and negative emotions) in their messages in social media forums receive more feedback than those who do not (Huffaker, 2010). Furthermore, research has also shown that users' attraction to emotional content is not limited to a particular domain. This means that users tend to repost information that has a greater emotional impact, regardless of what the information is about (Milkman and Berger, 2014). We believe that this common rule also applies to the sharing behavior of debunking information. Hence, the following hypothesis is proposed:

> *H2a: Debunking information with positive or negative sentiment is shared more often than the sharing of information with a neutral sentiment.*

Regarding the influence of positive and negative emotions on information-sharing behavior, some studies have shown that content that conveys positive emotions receives more attention and triggers higher levels of arousal, which can further influence feedback and social sharing behavior (Kissler et al., 2007; Berger, 2011; Bayer et al., 2012; Dang-Xuan and Stieglitz, 2012; Stieglitz and Dang-Xuan, 2013; Zollo et al., 2017). Therefore, we propose the following hypothesis:

> *H2b: Debunking information with a positive sentiment is shared more often than that with a negative sentiment.*

MATERIALS AND METHODS

Data Collection

We chose Sina Weibo because of its popularity in China and its unique "repost" feature as a powerful mechanism for sharing information (Pulido Rodríguez et al., 2020). In the context of Sina Weibo, users first post the original post-debunking information (information used to debunk misinformation). The original post is then disseminated to a new set of audience through re-posting, thus achieving the purpose of sharing and spreading the debunking information.

Through the Zhiwei Data Sharing Platform (Zhiwei Data, China) with Sina Info's Enterprise Interface API, we collected data from posts on Sina Weibo between January 2020 and June 2021, carrying rumors that were eventually proven to be false. The three most widely spread rumors were as follows:

1. The Dragon Boat Festival, held by the University of Electronic Science and Technology (UESTC), was thought to invite Chinese female students to accompany international male students. This was later confirmed to be false information.
2. Mr. Yuan Longping was thought to have died while he was still receiving treatment in the hospital; this was later confirmed to be false information.
3. COVID-19 "Patient Zero" was thought to be a graduate student at the Wuhan Institute of Virology, which was later confirmed to be false information.

The dataset contained 4,586 original microblogs (489 posts about "UESTC," 3 190 posts about "Yuan Longping," and 907 posts about "Wuhan Institute of Virology").

Identification of Rumors and Debunking Messages

We grouped the relevant microblogs into five categories in line with Jung et al.'s (2020) classification. This included the following:

1. Rumor: false information is published, no doubt is expressed.
2. Debunking message: a rumor is denied, or a correction is published, the rumor is corrected in the post itself or through a linked article.
3. Uncertainty about rumor: the rumor is published, but it is questioned.
4. Uncertainty about debunking message: the debunking message is published, but it is questioned.
5. Others: jokes, unclear statements, and opinions.

We used manual tagging to filter the debunking information from the collected posts. First, three researchers in the field of social media (two Ph.D. students and one expert from Zhiwei Technologies Ltd.) annotated the 4,586 posts. We then used Cohen's Kappa to ensure that the annotation scheme was consistent and valid. Next, we excluded *rumor*, *uncertainty about debunking message*, and *others* (1, 4, and 5 in the classification above), while retaining *debunking message* and *uncertainty about rumor* (2 and 3 above). Finally, 1,196 pieces of debunking information (including 304 of the UESTC, 447 of Yuan Longping, and 445 of the Wuhan Institute of Virology) were obtained.

Identification of Account Roles and Debunking Message Types

Mirbabaie et al. (2014) identified five main backgrounds that debunkers may belong to. These included the following:

1. Emergency service organizations.
2. Media organizations (including journalists and bloggers).
3. Political groups and unions.
4. Individuals (political engagement or personal involvement).
5. Business organizations.

In this study, some adjustments were made to this classification method to consider microblog authentication types. The authenticated accounts were further divided into three categories:

1. Government
2. Media
3. Celebrity

Thus, debunkers were finally classified into the following four categories:

1. Ordinary accounts
2. Celebrity accounts
3. Media accounts
4. Government accounts

Three researchers examined the account types of debunkers for 1,196 debunked messages and ensured a consistent tagging scheme through Cohen's Kappa.

Sentiment Analysis

Sentiment analysis is a popular technique that is used to detect positive, neutral, or negative emotions from text. In this case, we sought to detect these emotions in social media content. For example, there are several algorithms specifically designed for short informal texts (Paltoglou and Thelwall, 2010; Hutto and Gilbert, 2014). Among these emotion analysis algorithms, Sentistrength is a promising one. The algorithm assigns positive $S^{+}(t)$ and negative $S^{-}(t)$ emotion scores to each piece of information and uses a single index to capture their polarity. That is, the emotional value $S(t)$ is defined as the difference between positive and negative emotion scores.

However, there are some defects in the current emotion analysis methods for information on social media. The defects could decrease the accuracy of classification. For instance, the accuracy of Sentistrength in capturing positive emotions is only 60% (Ferrara and Yang, 2015). This may be caused by several factors, for example, the informality of the network text and the ambiguity of the same words used under different backgrounds. To overcome these shortcomings, this study calculated positive and negative emotionally charged words in each text based on the improved emotional dictionary. It took the difference

between the two as the final emotional tendency. To calculate the emotional value, we used the following equation:

$$S(i) \quad = S^{+}(i) - S^{-}(i),$$

where $S(i)$ indicates the emotional value; $S^{+}(i)$ indicates the number of positive emotional words in the article I; and $S^{-}(i)$ indicates the number of negative emotional words in the article i.

We used the National Taiwan University Simplified Chinese Dictionary and the Simplified Chinese Emotion Dictionary of Taiwan University and made the following amendments to the dictionary based on the characteristics of each rumor.

1. Emotional symbols play an important role in emotional expression. We thus converted the emotional symbols in the text into machine-recognizable words and incorporated them into the emotional value calculation.
2. For different rumors, we randomly selected one-third of the texts, analyzed their expression characteristics, and added words with obvious satire and ridicule to the dictionary.
3. When debunking a rumor, it is necessary to first describe it. In this context, the emotional words in the rumor cannot represent the emotional tendency of the debunking information. Therefore, we made some adjustments. The emotional words in the original rumor were not calculated as the emotional value of the debunking information. Based on the above improvements, we used Python to calculate the emotional polarity of each text and labeled it as positive, middle, or negative according to its emotional polarity value.

RESULTS

Preliminary Analysis

All statistical analyses were performed using Stata version 16.1. Samples 1, 2, and 3 represent rumors 1, 2, and 3, respectively. The sample number, mean, standard deviation, and maximum and minimum values of the major variables in the three rumor samples are shown in **Table 1**.

The preliminary basic statistics of sample 1 revealed 304 observations, and the average number of reposts was 9,586. The proportions of celebrities, media, and government accounts were 27.3, 15.1, and 4.6%, respectively. Positive emotion accounted for 34.9%, and negative emotion accounted for 2.3% of the sample. In sample 2, there were 447 observations, and the average number of reposts was 40,497. The proportions of celebrities, media, and government accounts were 28.0, 12.5, and 2.0%, respectively, and the proportions of positive and negative emotions were 80.5 and 5.1%, respectively. In sample 3, there were 445 observations, and the average count of reposts was 6,865. The proportions of celebrities, media, and government accounts were 22.7, 65.8, and 3.8%, respectively, and the proportions of positive and negative emotions were 8.3 and 38.2%, respectively.

TABLE 1 | Descriptive statistics of the major variables.

Sample	Variable	Obs	Mean	Std. Dev.	Min	Max
Sample 1	Y	304	9.586	79.99	0	1,240
	ac1	304	0.273	0.446	0	1
	ac2	304	0.151	0.359	0	1
	ac3	304	0.046	0.21	0	1
	s1	304	0.349	0.477	0	1
	s2	304	0.023	0.15	0	1
	Fol	304	1212264.9	6892123.9	2	1.03E+08
Sample 2	Y	447	40.497	283.375	0	4,625
	ac1	447	0.28	0.449	0	1
	ac2	447	0.125	0.331	0	1
	ac3	447	0.02	0.141	0	1
	s1	447	0.805	0.396	0	1
	s2	447	0.051	0.221	0	1
	Fol	447	2091211.9	9602701.3	0	1.03E+08
Sample 3	Y	445	6.865	66.674	0	1,088
	ac1	445	0.227	0.419	0	1
	ac2	445	0.658	0.475	0	1
	ac3	445	0.038	0.192	0	1
	s1	445	0.083	0.276	0	1
	s2	445	0.382	0.486	0	1
	fol	445	5442990.3	13975008	1	1.20E+08

Y represents the number of reposts.
ac1–ac3 represent celebrity-, media-, and government-type accounts, respectively, 0 or 1.
s1 and s2 represent negative and positive sentiment, respectively, 0 or 1.
Fol represents the number of followers.

Mediation Model Testing

We used the bootstrap approach to test for mediating effects. The bootstrap test is one of the coefficient product tests among the mediating effect tests. It was the most common mediating effect test at the time of this study. It is based on the theoretical concept of standard error, which treats the large-size sample as the total and conducts put-back sampling to obtain a more accurate standard error (Biesanz et al., 2010). The independent variable is the type of account (divided into ordinary, celebrity, media, and government), which is a four-category independent variable. The mediating variable was the number of followers, and the dependent variable was the number of reposts. Since dependent variables take a wide range of values, they can be treated as continuous variables.

Using the ordinary account-type as reference, we examined the mediating role of follower count between celebrity, media, and government accounts and the number of reposts (Fang et al., 2017).

A number of factors influence the sharing behavior, such as text sentiment, message tagging, whether it contains a URL, whether it contains an image, and whether it contains a video (Stieglitz and Dang-Xuan, 2013; Ruths and Pfeffer, 2014; Ferrara and Yang, 2015; Brady et al., 2017; Howard et al., 2018; Lazer et al., 2018). Unlike regular information, debunking information has its own characteristics. Some studies have shown that the more quickly a rumor is debunked, the more effective the debunking was (Jung et al., 2020). Therefore, we added the

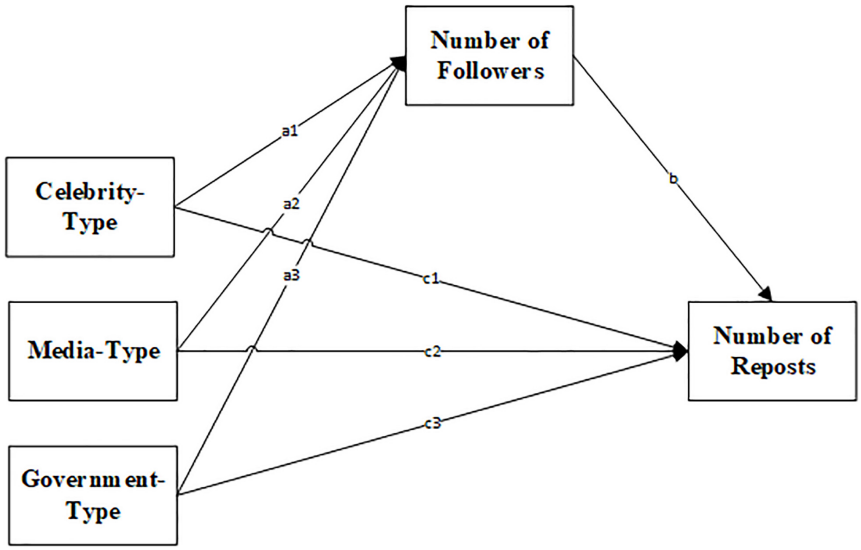


FIGURE 1 | The mediation mode. a × b represents the value of the indirect effect (which is the value of ind_eff in **Table 2**), c represents the value of the direct effect (which is the value of dir_eff in **Table 2**). For example, in Sample 1, the indirect effect a1 × b of the celebrity-type account on the number of reposts is ind_eff = 0.457 and is significant at the 1% level, and the direct effect c1 is dir_eff = 0.054 and is not significant.

delay in posting the debunking information as a control variable. Additionally, we included the following variables as control variables: text sentiment, whether the message contained a tag, whether the message contained a URL, whether the message contained an image, and whether the message contained a video. The mediation effect model is shown in **Figure 1**.

Table 2 shows the results of the mediation effects test using the bootstrap approach for the three rumor samples.

In sample 1, the relative direct effects of the three account types—celebrity, media, and government—on the number of reposts were not significant. The relative indirect effects on the number of reposts were significant (a1 × b = 0.457, $p < 0.01$; a2 × b = 0.634, $p < 0.01$; a3 × b = 0.289, $p < 0.01$). In sample 2, the relative direct effects of the three account types on the number of reposts were not significant. The relative indirect effects on the number of reposts were significant (a1 × b = 0.604, $p < 0.01$; a2 × b = 1.137, $p < 0.01$; a3 × b = 0.845, $p < 0.01$). Thus, in samples 1 and 2, the mediating effect of follower count on the relation between the three types of accounts—celebrity, media, and government—and number of reposts was significant, using the ordinary account type as reference. In sample 3, the relative direct effect of the three account types on the number of reposts ($c1' = -0.52$, $p < 0.01$; $c2' = -0.711$, $p < 0.01$; $c3' = -0.671$, $p < 0.01$) was significant, and the relative indirect effect on the number of repost (a1 × b = 0.797, $p < 0.01$; a2 × b = 0.996, $p < 0.01$; a3 × b = 0.634, $p < 0.01$) was also significant, and the indirect and direct effects are shown as opposite signs. In sample 3, the suppression effect of follower count between the three types of accounts and the number of reposts was significant, using the ordinary account type as reference. Suppression means the total effect was masked when indirect and direct effects were significant and opposite (MacKinnon et al., 2002; MacKinnon, 2008).

Therefore, we can conclude that the number of followers plays a mediating, or a suppressive, role between the three account types (celebrity, media, and government) and the number of reposts when the ordinary account type is used as the reference level. Thus, H1 was verified.

TABLE 2 | Results of bootstrap.

	Var	Effect	Coef.	S.E.	*z*	95% CI (BC)
Sample1	ac1	ind_eff	0.457	0.133	3.43***	[0.244, 0.784]
		dir_eff	0.054	0.149	0.36	[–0.224, 0.342]
	ac2	ind_eff	0.634	0.177	3.58***	[0.338, 1.070]
		dir_eff	0.181	0.26	0.69	[–0.305, 0.715]
	ac3	ind_eff	0.289	0.105	2.75***	[0.142, 0.584]
		dir_eff	0.392	0.312	1.26	[–0.150, 1.079]
Sample2	ac1	ind_eff	0.604	0.13	4.66***	[0.387, 0.908]
		dir_eff	–0.196	0.105	–1.87	[–0.410, 0.004]
	ac2	ind_eff	1.137	0.25	4.54***	[0.687, 1.701]
		dir_eff	0.695	0.397	1.75	[–0.055, 1.525]
	ac3	ind_eff	0.845	0.242	3.49***	[0.438, 1.448]
		dir_eff	0.009	0.673	0.01	[–1.149, 1.552]
Sample3	ac1	ind_eff	0.797	0.177	4.51***	[0.515, 1.213]
		dir_eff	–0.52	0.205	–2.54**	[–0.972, –0.173]
	ac2	ind_eff	0.996	0.215	4.63***	[0.631, 1.487]
		dir_eff	–0.711	0.201	–3.54***	[–1.146, –0.343]
	ac3	ind_eff	0.634	0.166	3.83***	[0.360, 1.012]
		dir_eff	–0.671	0.244	–2.75***	[–1.132, –0.173]

$^{***}p < 0.01$; $^{**}p < 0.05$; $^{*}p < 0.1$.
ac1-ac3 represent celebrity-, media-, and government-type accounts, respectively, 0 or 1.
ind_eff represents the value of the indirect effect.
dir_eff represents the value of the direct effect.

Regression Analysis

Negative Binomial Regression Analysis

To test H2a and H2b, which state that debunking information with emotional overtones (positive or negative) receive more reposts than neutral messages and that debunking information with positive sentiment is shared more often than those with negative sentiment, respectively, the following variables were constructed: as the dependent variable, the amount of reposted debunking information; as the independent variable, the emotional polarity of the debunking information.

We included the following as control variables: whether the account was certified, whether the message contained a tag, whether the message contained a URL, whether the message contained an image, whether the message contained a video, and the time difference between rumor and debunking information.

We used a regression model to test H2a and H2b. As our dependent variable represented the number of reposts of one piece of information, which was a non-negative integer, and the variance of the number of times it was forwarded in the three samples was far greater than the mean value, as shown in **Table 1**, we used a negative binomial regression model for all the three samples. The results are shown in **Tables 3**–**5**.

The regression results showed that in sample 1, both negative and positive sentiments had a positive effect on the reposting of information compared to a neutral sentiment (positive: coef = 2.289, SE = 0.592, $p < 0.01$; negative: coef = 0.751, SE = 0.434, $p < 0.1$). Moreover, we observed that the coefficient of positive sentiment was 3.05 times higher than that of negative sentiment. These results demonstrate that positive or negative debunking information had a higher number of reposts, compared to neutral sentiment, and that positive sentiment had a boosting effect on the number of reposts in sample 1. In sample 2, we repeated the process above. The results from sample 2 were similar to those from sample 1. Specifically, both positive and negative sentiment received more reposts, relative to neutral sentiment (positive: coef = 2.377, SE = 0.74, $p < 0.01$; negative: coef = 1.738, SE = 0.455, $p < 0.01$). The coefficient value of positive sentiment was observed to be 1.37 times higher than negative sentiment. In sample 3, the facilitation effect of positive or negative sentiment on information forwarding, relative to neutral sentiment, remained significant (positive: coef = 0.942, SE = 0.592, $p < 0.05$; negative: coef = 2.526, SE = 0.786, $p < 0.01$). However, unlike samples 1 and 2, we found that the coefficient of positive sentiment was 0.373 times higher than the coefficient of negative sentiment; that is, negative sentiment had a greater impact than positive sentiment on the sharing behavior of debunking information. Therefore, H2a was accepted, while H2b was not accepted.

TABLE 3 | Negative binomial regression results: sample 1.

y	Coef.	S.E.	*t*-value	95% CI
s1	751	0.434	1.73*	[–0.101, 1.602]
s2	2.289	0.592	3.86***	[1.128, 3.45]
d_std	–0.766	0.184	–4.16***	[–1.127, -0.405]
lnfol	0.214	0.06	3.59***	[0.097, 0.331]
ac	0.758	0.503	1.51	[–0.227, 1.743]
url	1.349	0.749	1.80*	[–0.118, 2.817]
tag	2.045	0.617	3.32***	[0.836, 3.254]
pic	1.659	0.458	3.63***	[0.762, 2.556]
vid	–0.49	0.671	–0.73	[–1.804, 0.824]
Constant	–5.002	0.742	–6.74***	[–6.457, –3.548]
lnalpha	1.898	0.179		[1.548, 2.249]
Mean dependent var		9.586	SD dependent var	79.990
Pseudo *r*-squared		0.138	Number of obs	304
Chi-square		148.790		0.000

****p < 0.01; **p < 0.05; *p < 0.1.*
s1 and s2 represent negative and positive sentiment, respectively, 0 or 1.
d_std, lnfol, ac, url, tag, pic, and vid are all control variables, where d_std represents the standardized delay in posting the debunking information.
lnfol represents the number of followers after taking logarithms.
ac represents whether the account is authenticated, 0 or 1.
url represents whether the message include URL, 0 or 1.
tag represents whether the message include tag, 0 or 1.
pic represents whether the message include pictures, 0 or 1.
vid represents whether the message include video,0 or 1.

TABLE 4 | Negative binomial regression results: sample 2.

y	Coef.	S.E.	*t*-value	95% CI
s1	1.738	0.455	3.82***	[0.847, 2.63]
s2	2.377	0.74	3.21***	[0.926, 3.828]
d_std	–0.902	0.212	–4.26***	[–1.317, –0.487]
lnfol	0.747	0.07	10.65***	[0.61, 0.885]
ac	–0.051	0.586	–0.09	[–1.199, 1.097]
url	–0.738	0.471	–1.57	[–1.662, 0.186]
tag	–0.333	0.63	–0.53	[–1.567, 0.902]
pic	–0.197	0.463	–0.42	[–1.105, 0.711]
vid	–1.022	0.623	–1.64	[–2.244, 0.2]
Constant	–8.361	0.932	–8.97***	[–10.188, –6.533]
lnalpha	1.852	0.136		[1.585, 2.119]
Mean dependent var		40.862	SD dependent var	284.628
Pseudo *r*-squared		0.188	Number of obs	447
Chi-square		484.377		0.000

****p < 0.01; **p < 0.05; *p < 0.1.*
s1 and s2 represent negative and positive sentiment, respectively, 0 or 1.
d_std, lnfol, ac, url, tag, pic, and vid are all control variables, where d_std represents the standardized delay in posting the debunking information.
lnfol represents the number of followers after taking logarithms.
ac represents whether the account is authenticated, 0 or 1.
url represents whether the message include URL, 0 or 1.
tag represents whether the message include tag, 0 or 1.
pic represents whether the message include pictures, 0 or 1.
vid represents whether the message include video, 0 or 1.

Model Robustness Tests

We further corroborated our findings by excluding alternative explanations and checking for robustness and consistency in a number of ways.

First, there may be concerns about the potential presence of heteroscedasticity, which could bias the standard errors of the estimates. Therefore, we used heteroscedasticity robust standard errors in all models.

Second, we checked the robustness of our findings using different models. We re-estimated using OLS and obtained results that were consistent with those in **Table 2**.

Finally, we investigated whether our findings were robust under different combinations of control variables. Therefore, we

TABLE 5 | Negative binomial regression results: sample 3.

y	Coef.	S.E.	*t*-value	95% CI
s1	2.526	0.786	3.21***	[0.986, 4.065]
s2	0.942	0.438	2.15**	[0.083, 1.801]
d_std	–.664	0.224	–2.97***	[–1.103, –0.226]
lnfol	0.67	0.091	7.37***	[0.492, 0.848]
ac	–2.638	1.12	–2.36**	[–4.833, –0.443]
url	–0.098	0.403	–0.24	[–0.889, 0.693]
tag	1.032	0.381	2.71***	[0.285, 1.78]
pic	–0.388	0.366	–1.06	[–1.106, 0.33]
vid	0.117	0.112	1.04	[–0.103, 0.337]
Constant	–7.319	1.011	–7.24***	[–9.3, –5.337]
lnalpha	2.162	0.136		[1.894, 2.429]
Mean dependent var		6.865	SD dependent var	66.674
Pseudo *r*-squared		0.101	Number of obs	445
Chi-square		98.614		0.000

****p < 0.01; **p < 0.05; *p < 0.1.*
s1 and s2 represent negative and positive sentiment, respectively, 0 or 1.
d_std, lnfol, ac, url, tag, pic, and vid are all control variables, where d_std represents the standardized delay in posting the debunking information.
lnfol represents the number of followers after taking logarithms.
ac represents whether the account is authenticated, 0 or 1.
url represents whether the message include URL, 0 or 1.
tag represents whether the message include tag, 0 or 1.
pic represents whether the message include pictures, 0 or 1.
vid represents whether the message include video, 0 or 1.

added gender and text length as new control variables and found that the results obtained in **Table 2** were consistent.

In summary, all tests indicate that our findings are robust and consistent.

Model Endogeneity Issues

The endogeneity of the model is not a serious problem owing to several reasons:

1. The independent and dependent variables have a clear chronological order, with the message being shared first and the reposts after, with no reverse causality.
2. The independent variable, text sentiment, is determined by the information publisher, while the dependent variable is determined by the forwarder, making it more difficult to have a third variable that affects both simultaneously, leading to pseudo-causality.
3. The use of data from the same sample in the same regression model prevents the appearance of factors that may affect both independent and dependent variables owing to the character of the rumor topic.

DISCUSSION

Discussion of the Results

First, using the ordinary account type as the reference, we observed a significant mediating or suppression effect of followers between the three types of accounts (celebrity, media, and government) and sharing behavior. In all the samples, these three account types had a significant positive effect on the number of reposts through the number of followers. The debunker's identity did not promote the sharing of debunking information while controlling for mediating variables. Information was shared to meet certain needs, and these needs motivated sharing the information in line with Tellis et al.'s (2019) findings. According to the hierarchical theory of needs, the lower the level of a need, the greater the effort of an individual paid for satisfying the need (Maslow, 1943, 1970, 1987). Specifically, in samples 1 and 2, the relative indirect effect of follower count between the three account types and sharing behavior was significantly positive, while the relative direct effect of account type on the number of reposts was not significant. Regarding rumor propagation in samples 1 and 2, people's needs, such as socialization and entertainment, fell in the belongingness level of Maslow's hierarchy of needs. In this context, users did not invest much energy in debunking information. The direct effect of the debunker's identity on sharing behavior was not significant. We believe that this was largely due to the oversight of sources—the information presented on social media was different from traditional media platforms.

In traditional media (e.g., TV news, newspapers, and news websites), the audience knows about the source of the information before they view the content. This affects how the audience treats the subsequent information. However, on social media, users do not choose a source of news. They get cocktails of stories from several different sources containing posts shared by friends, articles from sources the users have read before, and articles from sources users have not chosen. These posts could be real or fake, with the intention of deliberately influencing users' opinions and actions (Kim and Dennis, 2019). Moreover, some studies suggest that the current design of social media platforms—where users present their immediate feedback after quickly scrolling through formal news or emotional content—may block people's minds from thinking about additional factors, such as the reliability of the source. This influences users' sharing behavior (Pennycook et al., 2021). Thus, when the information meets the needs of the user, the confusing source of debunking information combined with the unique way in which users navigate information on social media will cause the user to focus primarily on the information. This could mean that the source has less influence on the sharing behavior.

In sample 3, the relative indirect effect of follower count between the three account types and sharing behavior was significantly positive, and the relative direct effect of account type on the number of reposts was significantly negative. We believe that this was due to the unique context of the rumor in sample 3. Unlike the circumstances of rumors in samples 1 and 2, in the context of a sudden public crisis, such as the COVID-19 outbreak, people's needs are concentrated at the physiological and safety needs levels. These are more powerful than belongingness needs and above. Hence, people would invest more energy in debunking information, leading to increased attention to sources of information. However, some studies suggest that when denied rumors were later proved to be factual information, users would reduce their trust in similar denials in the future (Wang and Huang, 2021). Users' beliefs about the information itself (i.e., confirmation bias) affect their perception of the source (Tormala et al., 2006, 2007). During the spread of the rumor regarding the Wuhan Institute of Virology, the early false denial of COVID-19 created distrust in the so-called "authoritative

channels." Here, the special identity of the debunker (celebrity, media, and government) becomes a hindrance to the sharing of debunking information. Thus, to increase the forwarding of debunking information on social media, the first step is to expand the potential audience—that is, the number of followers—rather than emphasizing the debunker's identity, which is commonly treated as a crucial factor.

Second, we found that debunking information with positive or negative emotions was forwarded more frequently than that with neutral emotions. This was consistent with previous studies that demonstrated the role of emotion in information diffusion (Bell et al., 2001; Huffaker, 2010; Berger and Milkman, 2012; Milkman and Berger, 2014). Our research confirmed that this finding also applies to the sharing of debunking information. Our findings were different from the findings of Ferrara and Yang (2015) and Zollo et al. (2017), who reported that information with positive sentiment always received more reposts. We found that it was not certain that information with positive emotions would always be shared more than that with negative emotions. We found that debunking information that was laced with negative emotions could be shared more: for example, in samples 1 and 2, positive emotions played a greater role, while in sample 3, negative emotions played a greater role. When users read the information, the emotion in it is perceived by them in two ways. One is perception of the emotion expressed by the debunking information, and the other is formed by the people's first impression of the subject of the rumor. The subjects of the three rumors in this study were the UESTC, Mr. Yuan Longping, and the Wuhan Institute of Virology. UESTC is a prestigious university in China, and Mr. Yuan Longping is a world-renowned expert in hybrid rice, but Wuhan Institute of Virology has a negative public reputation owing to some previous mishaps, such as the widespread mistrust caused by its fake announcement that "Shuanghuanglian" could treat COVID-19. The bias effect indicates that when people subjectively support a certain point of view, they tend to search for information that supports it as well and ignore the opposing view. The bias effect will cause an anchoring effect; that is, people prioritize their first impression while making decisions or judgments. Therefore, we believe that the first impression of the subjects in rumors may affect the forwarding behavior of information containing different emotional tendencies. When people perceive that the image of the subject tends to be positive, debunking information containing positive emotions such as blessings, encouragement, and praise conforms to people's first impression of the subject and is easily recognized and forwarded. When the subject's image tends to be negative, it is difficult to obtain people's trust for the debunking information that expresses positive emotions due to the bias effect. People may tend to repost information that contains negative sentiments such as warnings, condemnation, and mockery of the person who posted the rumor. It would be interesting to empirically test this hypothesis in future studies. The positive correlation between emotion and forwarding frequency of debunking information has highlighted the significance of using emotional expression for debunking information to obtain more reposts. Further consideration of the use of positive or negative sentiment in a particular situation may be required.

Implications

From a theoretical perspective, this study provides a conceptually grounded and empirically tested mediation model and a negative binomial regression model to explain the influence of a debunker's identity and the emotional content in the message on the sharing behavior of debunking information on social media (Sina Weibo). It attempts to bridge a gap in research on the behavior of debunking information on social media.

From a practical perspective, the study has important implications for Chinese social media. It is especially useful to agencies involved with emergency response agencies for its insights on the packaging and management of debunking information on social media, for wider reach and expanded impact. From the perspective of "who"—the debunkers' identity—previous research found that the source of an article affected the extent to which readers trusted it. This in turn influences users' engagement with the article (they may, for example, decide to read, like, comment, and share). However, the finding was based on laboratory experiments, which might have generalizability issues in the real world (Kim and Dennis, 2019). In this study, we used actual data to test the hypotheses. We followed actual acts of sharing of real data on social media. After controlling the mediating variables (number of followers), we found that the identity of the debunker did not improve the sharing behavior. This may be due to the unique way in which information is presented on social media. The implications for those involved with emergency services are that when debunking information on social media, expanding the audience and engaging the public are the most reliable focal points.

Second, from the perspective of "what"—the content of debunking information—the emotional value of the message will influence the extent to which it is shared (Brady et al., 2017). We found that information that was laced with emotional value always received more reposts. This finding has implications for the content generation of debunking information. Those involved with debunking rumors on social media will benefit from this finding. While the finding on emotional messaging is not novel, we have confirmed its value in debunking rumors on social media.

Limitations and Future Directions

This study has some limitations. First, our analyses were based on data from only three rumor spreads, which may raise the issue of overgeneralization, However, given that Weibo is a very popular social media platform and the rumors we selected were widespread, the issue the findings pass the test of generalization. Future studies could, however, validate the findings further. Second, only one of the three rumors involved a sudden public crisis event. Accordingly, the impact of the debunker's identity on the sharing behavior in a sudden public crisis event requires further in-depth research. For example, using the ordinary account as a reference, it remains to be seen in what scenarios the number of followers has a mediating effect and in what scenario it has a suppression effect. Finally, this study did not investigate the reasons for the different effects of the same affective polarity (positive or negative) on sharing behavior in the

context of different rumors. Future research could focus on the underlying reasons for the variability in the mechanisms by which emotions influence sharing behavior in different contexts.

CONCLUSION

This manuscript advances research on debunkers' identity and information sharing behavior through the number of followers as a mediating variable. Related to this is how emotions in debunking information affect reception of the message and message sharing. It makes useful contribution for strategic consideration by those involved with debunking rumors on social media.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

FC: study conception, data analysis, and write the manuscript. XW: contribution to study conception. GY: study conception, contribution to data analysis and the manuscript. All authors have approved the final version of the manuscript and its submission.

FUNDING

This research was funded by the National Natural Science Foundation of China (Grant No. 72074060).

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2021.783415/full#supplementary-material

REFERENCES

Allen, J., Howland, B., Mobius, M., Rothschild, D., and Watts, D. J. (2020). Evaluating the fake news problem at the scale of the information ecosystem. *Sci. Adv.* 6:eaay3539. doi: 10.1126/sciadv.aay3539

Andrews, C. A., Fichet, E. S., Ding, Y., Spiro, E. S., and Starbird, K. (2016). "Keeping up with the tweet-dashians: the impact of "official" accounts on online rumoring," in *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing – CSCW '16, 2016*. (New York, NY: Association for Computing Machinery), 451–464. doi: 10.1145/2818048.2819986

Aral, S., Muchnik, L., and Sundararajan, A. (2009). Distinguishing influence-based contagion from homophily driven diffusion in dynamic networks. *Proc. Natl Acad. Sci. U.S.A.* 106, 21544–21549. doi: 10.1073/pnas.0908800106

Arif, A., Robinson, J. J., Stanek, S. A., Fichet, F. S., Townsend, P., Worku, Z., et al. (2017). "A closer look at the self-correcting crowd," in *Proceedings of the 2017 ACM Conference on Computer Supported Cooperative Work and Social Computing – CSCW '17, 2017*. (New York, NY: Association for Computing Machinery), 155–168. doi: 10.1145/2998181.2998294

Bayer, M., Sommer, W., and Schacht, A. (2012). A. font size matters – emotion and attention in cortical responses to written words. *PLoS One* 7:e36042. doi: 10.1371/journal.pone.0036042

Bell, C., Sternberg, E., and Sternberg, E. (2001). Emotional selection in memes: the case of urban legends. *J. Pers. Soc. Psychol.* 81, 1028–1041. doi: 10.1037/0022-3514.81.6.1028

Berger, J. (2011). Arousal increases social transmission of information. *Psychol. Sci.* 22, 891–893. doi: 10.1177/0956797611413294

Berger, J., and Milkman, K. L. (2012). What makes online content viral? *J. Mark. Res.* 49, 192–205. doi: 10.1509/jmr.10.0353

Biesanz, J. C., Falk, C. F., and Savalei, V. (2010). Assessing mediational models: testing and interval estimation for indirect effects. *Multivariate Behav. Res.* 45, 661–701. doi: 10.1080/00273171.2010.498292

Brady, W. J., Wills, J. A., Jost, J. T., Tucker, J. A., and Van Bavel, J. J. (2017). Emotion shapes the diffusion of moralized content in social networks. *Proc. Natl Acad. Sci. U.S.A.* 114, 7313–7318. doi: 10.1073/pnas.1618923114

Burton, J. W., Cruz, N., and Hahn, U. (2021). Reconsidering evidence of moral contagion in online social networks. *Nat. Hum. Behav.* [Epub ahead of print]. doi: 10.1038/s41562-021-01133-5

Dang-Xuan, L., and Stieglitz, S. (2012). "Impact and diffusion of sentiment in political communication – an empirical analysis of political weblogs," in *Proceedings of the 6th International AAAI Conference on Weblogs and Social Media*, eds N. B. Ellison, J. g. Shanahan, and z. Tufekci (Palo Alto, CA: AAAI Press), 427–430.

Fang, J., Wen, Z., and Zhang, M. (2017). Mediation analysis of categorical variables. *Psychol. Sci.* 40, 471–477.

Ferrara, E., and Yang, Z. (2015). Quantifying the effect of sentiment on information diffusion in social media. *PeerJ Comput. Sci.* 1:e26. doi: 10.7717/peerj-cs.26

Hoover, J., Portillo-Wightman, G., Yeh, L., Havaldar, S., Davani, A. M., Lin, Y., et al. (2020). Moral foundations Twitter corpus: a collection of 35k tweets annotated for moral sentiment. *Soc. Psychol. Personal. Sci.* 11, 1057–1071. doi: 10.1177/1948550619876629

Hovland, C. I., Janis, I. L., and Kelley, H. H. (1953). *Communication and Persuasion: Psychological Studies of Opinion C hange*. New Haven, CT: Yale University Press.

Howard, P. N., Woolley, S., and Calo, R. (2018). Algorithms, bots, and political communication in the US 2016 election: the challenge of automated political communication for election law and administration. *J. Inf. Technol. Politics*. 15, 81–93. doi: 10.1080/19331681.2018.1448735

Huffaker, D. (2010). Dimensions of leadership and social influence in online communities. *Hum. Commun. Res.* 36, 593–617. doi: 10.1111/j.1468-2958.2010.01390.x

Hunt, K., Wang, B., and Zhuang, J. (2020). Misinformation debunking and cross-platform information sharing through Twitter during hurricanes Harvey and Irma: a case study on shelters and ID checks. *Nat. Hazards* 103, 861–883. doi: 10.1007/s11069-020-04016-6

Hutto, C., and Gilbert, E. (2014). "Vader: a parsimonious rule-based model for sentiment analysis of social media text," in *Proceedings of the International AAAI Conference on Weblogs and Social Media*, Ann Arbor, MI, 216–225.

Jung, A. K., Ross, B., and Stieglitz, S. (2020). Caution: rumors ahead—a case study on the debunking of false information on Twitter. *Big Data Soc.* 7, 1–15. doi: 10.1177/2053951720980127

Kassam, N. (2020). *Disinformation and Coronavirus: The Dilution of Information on the Internet is Currently Posing a Risk to Global Health and Safety*. Available online at: https://www.lowyinstitute.org/the-interpreter/disinformation-and-coronavirus, (accessed May 31, 2020)

Kim, A., and Dennis, A. R. (2019). Says who? The effects of presentation format and source rating on fake news in social media. *MIS Q.* 43, 1025–1039. doi: 10.25300/MISQ/2019/15188

Kissler, J., Herbert, C., Peyk, P., and Junghöfer, M. (2007). Buzzwords: early cortical responses to emotional words during reading. *Psychol. Sci.* 18, 475–480. doi: 10.1111/j.1467-9280.2007.01924.x

Kunitski, M., Eicke, N., Huber, P., Köhler, J., Zeller, S., Voigtsberger, J., et al. (2019). Double-slit photoelectron interference in strong-field ionization of the neon dimer. *Nat. Commun.* 10:1. doi: 10.1038/s41467-018-07882-8

Lasswell, H. D. (1948). "The structure and function of communication in society," in *The Communication of Ideas*, ed. L. Bryson (New York, NY: Harper and Row), 37–51.

Lazer, D. M. J., Baum, M. A., Benkler, Y., Berinsky, A. J., Greenhill, K. M., Menczer, F., et al. (2018). The science of fake news. *Science* 359, 1094–1096. doi: 10.1126/science.aao2998

MacKinnon, D. P. (2008). *Introduction to Statistical Mediation Analysis*. Mahwah, NJ: Erlbaum.

MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., and Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychol. Methods* 7, 83–104. doi: 10.1037/1082-989X.7.1.83

Martel, C., Pennycook, G., and Rand, D. G. (2020). Reliance on emotion promotes belief in fake news. *Cogn. Res. Princ. Implic.* 5:47. doi: 10.1186/s41235-020-00252-3

Maslow, A. H. (1943). A theory of human motivation. *Psychol. Rev.* 50, 370–396. doi: 10.1037/h0054346

Maslow, A. H. (1970). *Motivation and Personality*. New York, NY: Harper & Row.

Maslow, A. H. (1987). *Motivation and Personality*, 3rd Edn. Delhi: Pearson Education, 69.

McCracken, G. (1989). Who is the celebrity endorser? Cultural foundations of the endorsement process. *J. Con. Res.* 16, 310–321. doi: 10.1086/209217

Mian, A., and Khan, S. (2020). Coronavirus: The spread of misinformation. *BMC Med.* 18:89. doi: 10.1186/s12916-020-01556-3

Milkman, K. L., and Berger, J. (2014). The science of sharing and the sharing of science. *Proc. Natl. Acad. Sci. U.S.A.* 111(Suppl. 4), 13642–13649. doi: 10.1073/pnas.1317511111

Mirbabaie, M., Ehnis, C., Stieglitz, S., and Bunker, D. (2014). "Communication roles in public events: a case study on Twitter communications," in *Information Systems and Global Assemblages: (Re)configuring Actors, Artefacts, Organizations:* IFIP WG 8.2 Working Conference on Information Systems, 2014, eds B. Doolin, E. Lamprou, N. Mitev, and L. McLeod (Heidelberg: Springer).

Paltoglou, G., and Thelwall, M. (2010). "A study of information retrieval weighting schemes for sentiment analysis," in *Proceedings of the 48th Annual Meeting of the Association for Computational Linguistics (ACL)*, Uppsala, 1386–1395.

Pennycook, G., Epstein, Z., Mosleh, M., Arechar, A. A., Eckles, D., and Rand, D. G. (2021). Shifting attention to accuracy can reduce misinformation online. *Nature* 592, 590–595. doi: 10.1038/s41586-021-03344-2

Pulido Rodríguez, C., Villarejo Carballido, B., Redondo-Sama, G., Guo, M., Ramis, M., and Flecha, R. (2020). False news around COVID-19 circulated less on Sina Weibo than on Twitter. How to overcome false information? *RIMCIS* 9, 107–128. doi: 10.17583/rimcis.2020.5386

Ruths, D., and Pfeffer, J. (2014). Social sciences. Social media for large studies of behavior. *Science* 346, 1063–1064. doi: 10.1126/science.346.6213.1063

Scherman, T. H. (1993). The authority effect: Poe and the politics of reputation in the pre-industry of American publishing. *Ariz. Q. J. Am. Lit. Cult. Theor.* 49, 1–19. doi: 10.1353/arq.1993.0024

Stieglitz, S., and Dang-Xuan, L. (2013). Emotions and information diffusion in social media – sentiment of microblogs and sharing behavior. *J. Manag. Inf. Syst.* 29, 217–248. doi: 10.2753/MIS0742-1222290408

Tellis, G. J., MacInnis, D. J., Tirunillai, S., and Zhang, Y. (2019). What drives virality (sharing) of online digital content? The critical role of information, emotion, and brand prominence. *J. Mark.* 83, 1–20. doi: 10.1177/0022242919841034

Tormala, Z. L., Briñol, P., and Petty, R. E. (2006). When credibility attacks: the reverse impact of source credibility on persuasion. *J. Exp. Soc. Psychol.* 42, 684–691. doi: 10.1016/j.jesp.2005.10.005

Tormala, Z. L., Briñol, P., and Petty, R. E. (2007). Multiple roles for source credibility under high elaboration: it's all in the timing. *Soc. Cogn.* 25, 536–552. doi: 10.1521/soco.2007.25.4.536

Vosoughi, S., Roy, D., and Aral, S. (2018). The spread of true and false news online. *Science* 359, 1146–1151. doi: 10.1126/science.aap9559

Wang, B., and Zhuang, J. (2018). Rumor response, debunking response, and decision makings of misinformed Twitter users during disasters. *Nat. Hazards* 93, 1145–1162. doi: 10.1007/s11069-018-3344-6

Wang, C., and Huang, H. (2021). When "fake news" becomes real: the consequences of false government denials in an authoritarian country. *Comp. Polit. Stud.* 54, 753–778. doi: 10.1177/0010414020957672

Wang, D., and Qian, Y. (2021). Echo chamber effect in the discussions of rumor rebuttal about COVID-19 in China: existence and impact. *J. Med. Internet Res.* 23, e27009. doi: 10.2196/27009

Weeks, B. E. (2015). Emotions, partisanship, and misperceptions: how anger and anxiety moderate the effect of partisan bias on susceptibility to political misinformation. *J. Commun.* 65, 699–719. doi: 10.1111/jcom.12164

Wu, S. (2020). False information dissemination, governance dilemma and breakthrough path in major public health emergencies – taking covid-19 epidemic as an example. *E Gov.* 09, 40–50. doi: 10.16582/j.cnki.dzzw.2020.09.004

Yuhong, M. A., Yuanyuan, Z., and Yarong, Q. (2019). Conformity effect and authoritative effect of rumor spreading in social network. *J. Comput. Appl.* 39, 232–238.

Zollo, F., Bessi, A., Del Vicario, M., Scala, A., Caldarelli, G., Shekhtman, L., et al. (2017). Debunking in a world of tribes. *PLoS One* 12:e0181821. doi: 10.1371/journal.pone.0181821

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

PERSPECTIVE
published: 24 January 2022
doi: 10.3389/fpubh.2021.791182

Japan's Slow Response to Improve Access to Inpatient Care for COVID-19 Patients

Shinji Nakahara[1]*, *Haruhiko Inada*[2], *Masao Ichikawa*[3] and *Jun Tomio*[4,5]

[1] Graduate School of Health Innovation, Kanagawa University of Human Services, Kawasaki, Japan, [2] Department of International Health, Johns Hopkins Bloomberg School of Public Health, Baltimore, MD, United States, [3] Department of Global Public Health, Faculty of Medicine, University of Tsukuba, Tsukuba, Japan, [4] Department of Public Health, Graduate School of Medicine, The University of Tokyo, Tokyo, Japan, [5] Department of Health Crisis Management, National Institute of Public Health, Wako, Japan

The coronavirus disease 2019 (COVID-19) pandemic has exposed various weaknesses in national healthcare systems across the globe. In Japan, this includes the inability to promptly mobilize the resources needed to provide inpatient care in response to the rapidly increasing number of patients. Combined with unclear entry points to healthcare, particularly in emergency cases, this has led to a situation in which access to healthcare is rapidly deteriorating. This study examined problems in Japan's healthcare delivery system. While Japan's healthcare resources (e.g., hospital beds and medical personnel) are comparable to those found in other high-income countries, progress has been slow in securing beds for COVID-19 patients. In addition, the number of beds has only recently reached the levels seen in Western countries. Factors related to slow resource allocation include dispersed existing medical resources (mainly in the private sector), the lack of collaboration mechanisms among private-dominant healthcare providers and public health agencies, an inadequate legal framework for resource mobilization, the insufficient quantification of existing resources, and undesignated entry points to healthcare systems. To better prepare for future disasters, including the next wave of COVID-19, Japan urgently needs to restructure its legal framework to promptly mobilize resources, accurately quantify existing resources, introduce coordination mechanisms with functional differentiations among all community stakeholders, and clearly designate entry points to healthcare.

Keywords: disaster medicine, private sector, preparedness, pandemic (COVID-19), healthcare system

OPEN ACCESS

Edited by:
Jarle Løwe Sørensen, University of South-Eastern Norway, Norway

Reviewed by:
Sulaiman Mouselli, Arab International University, Syria
Masayuki Ozaki, Komaki City Hospital, Japan
Shinichi Tanihara, Kurume University, Japan

***Correspondence:**
Shinji Nakahara
snakahara-tky@umin.net

Specialty section:
This article was submitted to Disaster and Emergency Medicine, a section of the journal Frontiers in Public Health

Received: *08 October 2021*
Accepted: *14 December 2021*
Published: *24 January 2022*

Citation:
Nakahara S, Inada H, Ichikawa M and Tomio J (2022) Japan's Slow Response to Improve Access to Inpatient Care for COVID-19 Patients. Front. Public Health 9:791182. doi: 10.3389/fpubh.2021.791182

INTRODUCTION

The coronavirus disease 2019 (COVID-19) pandemic has forced countries around the world to respond with the full extent of their respective healthcare abilities, especially to handle surges in the number of patients. This has highlighted various organizational differences between systems. For example, in the United Kingdom (UK), the command-and-control mechanism of its public healthcare system was employed to mobilize existing resources (e.g., reorganizing healthcare provisions by minimizing routine services); meanwhile, the National Health Service contracted private hospitals to secure block-bought hospital beds, thus increasing the overall capacity to treat COVID-19 patients (1). In the United States (US), various partnerships among public agencies and

private-dominant healthcare providers have efficiently functioned to handle similar issues (2, 3).

In contrast, Japan's healthcare system only achieved slow progress in reallocating the medical resources needed to deal with the surge of COVID-19 patients (4). This is not because there has been less disease spread in Japan, as the reported number is unreliable due to limited testing, rather, issues have likely arisen due to a combination of structural issues in the healthcare system and insufficient preparedness in effectively appropriating existing resources in cases of emergency. In this regard, reports have shown that an increased number of patients were waiting for hospitalization during the fifth wave of the pandemic in Tokyo, as of August 2021 (5). Consequently, many of these individuals had to receive treatment at home and not a few at-home deaths were reported (4).

Thus, the pandemic has exposed critical weaknesses in Japan's healthcare system, many of which were masked by previous achievements, including one of the best populational health statuses in the world at a relatively low cost (6, 7). The nation must quickly address problems that have become clear due to COVID-19, both to improve the delivery of health services under normal conditions and prepare for other pandemics and disasters that may arise in the future. As such, this paper tries to clarify and discuss specific problems in Japan's healthcare delivery system, particularly as compared to situations in the UK and US.

CONTEXT: JAPAN'S HEALTH SYSTEM

Japan's healthcare system can be described as an entity with various similarities to the systems employed in the UK and US; in other words, it is somewhere in between these systems. For example, health service facilities are mostly privately owned, as is the case in the US system (**Table 1**) (8). Leaving healthcare delivery to the private sector may improve physical access to healthcare services, with a larger number of hospitals than both the UK and US at a relatively low cost to the government. On the other hand, health financing is accomplished through a public health insurance system that covers the entire population, as is done in the UK system, although the UK system differs in that it is tax-based. Here, insurance coverage has ensured service provisions at official prices, even in private hospitals, which may substantially reduce the financial barriers to healthcare services (7).

Including the number of physicians and nurses per capita, Japan's healthcare resources are comparable to those found in the UK and US; even further, the number of hospital beds per capita is much higher than in the UK and US (**Table 1**). This relatively large number of hospital beds is likely the result of underdeveloped role differentiation for inpatient beds. Physician-to-bed and nurse-to-bed ratios are quite low in Japan, showing that a large proportion of beds are used for long-term care, which requires fewer human resources than acute care. The actual number of acute care (curative) beds should be smaller than that shown in **Table 1**, but this information is not available in the statistical data.

TABLE 1 | Hospitals, hospital beds, COVID-19 patients, and bed occupancies in Japan, the UK, and the US.

	Japan[a]	UK[b]	US[c]
Population (millions)	126	66	327
All hospitals (n)	8,300	1,978	6,146
Publicly owned hospitals (n)	1,524	1,978	1,421
Proportion in all hospitals	18.4%	100.0%	23.1%
Total hospital beds (n)	1,620,040	162,723	924,107
Per 1,000 population	12.8	2.4	2.8
Curative beds[d] (n)	977,048	–	802,927
Per 1,000 population	7.7	–	2.5
Publicly owned beds (n)	442,741	162,723	197,865
Per 1,000 population	3.5	2.4	0.6
Physicians (n)	315,406	203,529	866,316
Per 1,000 population	2.49	2.95	2.64
Nurses (n)[e]	1,487,444	567,803	3,923,300
Per 1,000 population	11.76	8.45	11.79
Physician-to-bed ratio (total hospital beds)[f]	0.2	1.3	0.9
Nurse-to-bed ratio (total hospital beds)	0.6	3.16	2.93
Maximum daily new confirmed cases[g]	23,083	59,829	251,085
Per one million population[g]	183	877	754
Maximum daily tests performed[h]	135,173	1,303,126	1,909,168
Per 1,000 population[h]	1.07	19.11	5.74
Maximum daily hospital bed occupancy[i]	24,488	39,254	133,210
Proportion in curative beds[j]	2.5%	24.1%	16.6%
Per one million population[i]	194	576	400

Data source: healthcare resource data were obtained from OECD (8); COVID-19 data were obtained from Our World in Data (9), except for Japanese data on hospital occupancy, which were obtained from the Ministry of Health, Labour and Welfare Japan (10).

[a] *Japanese data on hospitals and beds were available for 2019. Excluding psychiatric hospitals, there were 7,246 hospitals and 1,374,988 hospital beds. The data on physicians and nurses were from 2018, while those for the nurse-to-bed ratio were from 2017.*

[b] *UK data (estimated number) on hospitals was from 2019, while those on hospital beds were from 2020. The data on physicians, nurses, and nurse-to-bed ratios were from 2020 (estimated).*

[c] *US data on hospitals and hospital beds were from 2018. The data for physicians were from 2019, while those for nurses were from 2020, and those for the nurse-to-bed ratio were from 2018.*

[d] *Curative beds in Japan have various functions (beds for the acute phase, recovery phase, and rehabilitation).*

[e] *Number of practicing nurses for Japan and the UK; and that of professionally active nurses for the US.*

[f] *These figures were calculated based on the numbers of physicians and beds (Japanese and the US data were in 2018, and UK data was in 2020).*

[g] *Data were obtained from Our World in Data (9). These are 7-day rolling averages. The data were from August 25, 2021 in Japan, January 9, 2021 in the UK, and January 8, 2021 in the US.*

[h] *Data were obtained from Our World in Data (9). These are 7-day rolling averages. The data were for August 30, 2021 in Japan, March 21, 2021 in the UK, and November 25, 2020 in the US.*

[i] *The data are from September 1, 2021 in Japan, January 18, 2021 in the UK, and January 14, 2021 in the US. The Japanese data were obtained from the Ministry of Health, Labour, and Welfare (10). UK and US data were obtained from Our World in Data (9).*

[j] *The denominator for the UK data is the number of total hospital beds, assuming that the beds in the UK are used for acute phase curative purposes.*

Compared to the UK and US systems, the most obvious difference in Japan is the lack of gatekeepers. The Japanese government has not assigned gatekeeper roles to primary physicians, meaning that patients can freely choose which medical facilities they wish to visit (i.e., a "free-access" system) (7, 11). Consequently, role differentiations have not emerged between hospitals and clinics; hospitals provide both ambulatory and hospitalized care, although the government has recently begun to introduce role differentiations (11). Among other factors, the insurance system, free access, and large numbers of hospitals and beds have created easy access to hospitalized care.

ACCESS TO HOSPITALIZED CARE FOR COVID-19 PATIENTS

Japan's healthcare system could not promptly meet the demands for hospitalized care that emerged following the patient upsurge created by the pandemic. As of September 1, 2021, reports from the fifth wave in Japan (August to September 2021) showed that the per capita number of maximum daily cases was only around 20% of what was reported in the UK (**Table 1**) (9, 10). However, this figure may be considerably underreported given the extremely small number of administered tests. From the same time period, Japan's maximum per capita hospital bed occupancy rate was only one-third of that shown in the UK and one-half of that shown in the US. This may reflect insufficient bed allocations rather than lower demands for hospitalized care, especially given the long waiting lists for hospital admission. Compared to numbers from the UK and US, a far lower proportion of curative beds (only 2.5%) were allocated to COVID-19 patients, although not all of these curative beds were actual acute care beds, as mentioned above. Overall, access to hospitalized care has worsened in Japan.

While gradual progress is being made in securing beds for COVID-19 patients in high-demand areas, the rate of improvement is too slow, as the number of available beds was still insufficient. In Tokyo, the maximum hospital bed occupancy was 4,218 as of September 1, 2021 (303 per million persons), which is slightly closer to the US level. However, given that more than 10,000 patients were on the waiting list for hospitalization in August (5), the actual bed requirement at that time was presumably two to three times higher (600–900 per million persons), which is somewhat higher than the maximum level in the UK (576 per million persons). Efforts have since continued to increase the number of secured beds in Tokyo, eventually reaching 6,583 (474 per million persons) as of September 8, 2021; thus matching the level in the US (10).

In terms of hospital access, a unique problem was also revealed in Japan's ambulance system. That is, no hospital emergency departments are designated as ambulance destinations. Rather, ambulance crews perform triage at the scene, then select an appropriate hospital based on the patient's conditions. Upon selection, crews must determine whether their patients will be accepted by sending an inquiry to the hospital (12), which may decline the patient based on its treatment abilities and bed vacancies. In the pandemic context, the number of cases requiring long inquiry processes greatly increased (12, 13). While emergency departments in other countries tended to experience overcrowding when large numbers of COVID-19 patients were transported by ambulance, patients in Japan had to remain at the scene for long periods of time while ambulance crews looked for appropriate hospital destinations. Due to the insufficient number of beds available for treating COVID-19, patients confirmed or suspected of having COVID-19 may thus wait for hours in an ambulance while still in front of their homes (14, 15).

IDENTIFYING THE PROBLEMS

Several characteristic features of Japan's healthcare system have complicated the ability to allocate resources and secure hospital access during the pandemic. There are five main areas of concern. First, the composition of mostly small- to medium-sized hospitals has made efficient resource reallocation difficult; here, resources are dispersed among these hospitals across communities. More than 80% of private and 50% of public hospitals contain <200 beds (**Table 2**) (16). Further, these hospitals do not employ experts in infectious disease or contain negative pressure rooms. In addition, approximately 40% of the beds in hospitals containing <200 are used for long-term care (16). As evident from these data and the overall small staff-to-bed ratios (smaller hospitals tend to have smaller ratios), the role of these hospitals is to provide sub-acute to long-term care: they just cannot deal with COVID-19 patients. Even with some abilities to provide acute care, directors of these hospitals may have been reluctant to accept COVID-19 patients by because of concerns about their insufficient ability to manage severe cases, the possible reduction of services to other diseases, and the risk of nosocomial infection from hospitalized COVID-19 patients. A survey conducted by the Ministry of Health, Labour and Welfare in January 2021 indicated that only 19.3% of private hospitals with acute care beds and <200 total beds had hospitalized COVID-19 patients (17).

Second, Japan's system is private-dominant and the government cannot forcibly mobilize medical resources. Most hospitals (79%) and clinics (96%) are owned by entities in the private sector (**Table 2**). Despite public subsidies, the practice of hospitalizing COVID-19 patients resulted in large revenue losses for many hospitals, which is a strong disincentive among independently financed private hospitals with small budgets (18). In addition, most national hospitals belong to independent external agencies; the majority of public hospitals are either small- to medium-sized or owned by independent agencies or public service organizations such as the Japan Red Cross Society and Japan Agricultural Cooperatives. Neither the national nor local governments have the legal authority to issue orders to hospitals that do not belong to them, and must instead rely on requests. As an exception, prefectural governors hold the legal authority to mobilize resources during major disasters, as outlined in the Disaster Relief Law. However, they cannot exercise this mechanism in the context of COVID-19, as a pandemic is not legally defined as a disaster.

Third, the lack of coordination mechanisms and partnerships among healthcare providers, public agencies, and local

TABLE 2 | Size of medical care facilities and bed types by ownership in Japan (2019).

	National hospitals[a]	Public hospitals[b]	Private hospitals[c]	Clinics[d]
Number of hospitals/clinics by hospital size[e]				
Total[f]	319	1,162	5,765	102,616
0 bed (n)	–	–	–	95,972
Proportion	–	–	–	93.5%
1–19 beds (n)	–	–	–	6,644
Proportion	–	–	–	6.5%
20–99 beds (n)	14	298	2,586	–
Proportion	4.4%	25.6%	44.9%	–
100–199 beds (n)	50	284	2,051	–
Proportion	15.7%	24.4%	35.6%	–
200–399 beds (n)	113	310	855	–
Proportion	35.4%	26.7%	14.8%	–
400 or more beds (n)	142	270	273	–
Proportion	44.5%	23.2%	4.7%	–
Number of beds by bed type				
Total[f]	125,533	301,461	857,169	90,825
General curative[g] (n)	116,886	273,222	497,739	82,943
Proportion	93.1%	90.6%	58.1%	91.3%
Tuberculosis (n)	1,773	1,635	962	–
Proportion	1.4%	0.5%	0.1%	–
Infectious disease (n)	169	1,515	204	–
Proportion	0.1%	0.5%	0.0%	–
Long-term care (n)	380	15,829	292,235	7,882
Proportion	0.3%	5.3%	34.1%	8.7%
Psychiatric (n)	6,325	9,260	66,029	–
Proportion	5.0%	3.1%	7.7%	–

The data source was a medical facility survey conducted in 2019 by the Ministry of Health, Labour and Welfare (16).

[a] This category includes not only hospitals directly affiliated with the Japanese government, but also those affiliated with independent administrative agencies under the jurisdiction of the national government and affiliated with national universities.

[b] This category includes local governments, health insurance organizations in the public sector, and public service organizations such as the Red Cross Society.

[c] This category includes non-profit-oriented medical corporations and health insurance organizations in the private sector.

[d] Private sectors account for 96.0% of all clinics.

[e] Hospitals are defined as medical care facilities with 20 or more beds. Clinics can be equipped with fewer than 20 beds. Psychiatric hospitals were excluded.

[f] Psychiatric hospitals were excluded.

[g] General curative beds are the remainder after excluding specialized beds (beds for infectious diseases, tuberculosis, long-term care, and psychiatric diseases); they are generally categorized as hospital beds intended for various functions (beds for acute phase, recovery phase, and rehabilitation).

governments impedes efficient resource utilization during public health emergencies. Japan's hospital system has traditionally consisted of small- to medium-sized hospitals that developed from clinics and provides self-contained services on an independent basis (7). As such, functional differentiation and coordination are still relatively nascent. Moreover, Japanese municipalities are primarily responsible for disaster responses, including medical care provisions, and must develop community disaster plans under the guidance of prefectural governments (19). However, there are currently no well-developed collaboration or coordination mechanisms between municipal governments and healthcare facilities at the community level; in many cases, there are no clear role definitions or command systems for dealing with patient surges (20). In addition, each municipality or prefecture is responsible for medical care in its jurisdiction, and inter-jurisdiction cooperation mechanisms do not exist (such mechanisms as wide-area patient transfer will be triggered in disasters but a pandemic is not legally defined as a disaster). Consequently, delays may occur when attempting inter-hospital or inter-jurisdiction transfers of COVID-19 patients. Particularly, delayed transfer of recovering patients from tertiary to secondary care hospitals resulted in mismatches between patient severity and hospital function, thus exacerbating the existing supply-demand imbalance in inpatient care.

Fourth, the lack of clearly designated entry points to the healthcare system has diminished access during the pandemic, which is the flip side to the "free access" system. Whereas, there are no strict gatekeeper roles allowing patients to visit any facility they wish (11), patients are required to select appropriate facilities due to premature functional differentiation and the referral network. At the beginning of the pandemic, many hospitals

and clinics declined febrile patients because their facilities were not appropriate entry points, meaning that patients should have instead chosen locations that better fit their needs (21). Although conditions are improving, many hospitals continue to decline febrile patients who are being transferred by ambulance, especially during surges of COVID-19 patients (5, 13). In such cases, the patients themselves or ambulance crews must identify facilities that will provide care to febrile patients. In general, the "free-access" provision may entail far fewer entry points to the healthcare system (at the discretion of providers) during public health emergencies, thus creating a situation of "concealed access." As such, service users may find themselves desperately searching for appropriate entry points (12).

Fifth, medical resources have not been accurately quantified, which may result in incongruent policymaking. At 7.7 per 1,000 persons, Japan appears to have more curative beds per capita than other countries. In reality, this may be an overestimation of Japan's total healthcare resources. Here, curative beds are those which remain after excluding beds for other purposes (infectious diseases, tuberculosis, psychiatry, and long-term care), meaning beds for general usage (11); some are not used for acute care, but are actually taken for rehabilitation or sub-acute care. The number of curative beds designated for acute phase patients should be smaller; a recent study estimated that there were actually 3.3 per 1,000 persons, which may be more accurate (18). The official statistics are likely inaccurate due to the insufficient classification of beds. This has created a seemingly contradictory situation in which a small number of beds are secured for COVID-19 patients despite a large overall number of hospital beds. Furthermore, mobilizing acute care beds for hospitalizing COVID-19 patients resulted in minimizing or postponing other health services, which may mean not only a lack of coordination, but also an absolute lack of resources to deal with a public health emergency while continuing regular services. These problems point to the urgent need for accurate resource assessments.

DISCUSSION: PROPOSITIONS FOR IMPROVEMENT

Japan is gradually securing the number of hospital beds needed to treat COVID-19 patients. Some areas have even matched the conditions achieved in the US and UK, with most of these being in urban locations. In addition, laws related to infectious disease control were amended in February 2021, such that prefectural governors now have the authority to strongly request that hospitals provide additional beds to accommodate COVID-19 patients. A telemedicine system was also introduced to support small- to medium-sized hospitals that do not employ experts in infectious disease and intensive care to provide appropriate care to COVID-19 patients and to control nosocomial infections. Following another legal amendment designed to facilitate the process, some prefectures have either already set up temporary COVID-19 hospitals or plan to do so in order to increase the number of available beds. Despite these efforts, Japan must still address the problem of inefficient resource usage, by restructuring the medical system to establish better disaster preparedness. Even if it is not currently possible to fundamentally alter the health service system itself (e.g., transitioning from private-dominant to public systems), some useful modifications are feasible. For example, policymakers may incorporate coordination mechanisms, strengthen referral networks, and clearly designate entry points to critical health systems during public health emergencies.

With a private-dominant healthcare delivery system similar to Japan's, the US may serve as a point of reference. Considering the different healthcare systems, we should learn from the coordination mechanisms rather than the system itself. Of note, the US has developed "healthcare coalitions" to coordinate between individual healthcare providers, public health agencies, emergency medical services, and emergency management agencies for health system preparedness. This is supported by the Hospital Preparedness Program, which is a federally funded nationwide initiative (2, 22) that facilitates collaboration among individual healthcare facilities, improves information sharing, and ensures the efficient reallocation of scarce resources in response to all types of public health emergencies. As such, this coordination mechanism among various stakeholders functions as a substitute for an organizational structure with command-and-control mechanisms, as found in public health service systems such as that employed in the UK. The US system may provide a suitable template for improving Japan's health service system.

Although Japanese and US healthcare providers share the similarity of private-dominance, we must pay attention to the differences in referring to the US. The biggest difference is the complexity of provider composition in Japan, in which there is a large number of small- to medium-sized hospitals that independently provide services and sometimes compete with one other in contrast to clear role differentiations among healthcare facilities in the US. Moreover, there are substantial regional variations in this composition. Each region should therefore create an applicable system through a bottom-up approach that involves support from local public health authorities (20). Combined with such region-specific disaster preparedness efforts, the coordination mechanism and governmental subsidies seen in the US healthcare coalitions would expedite functional differentiation and augment the development of inter-hospital resource reallocation mechanisms.

Further, existing laws should be amended to redefine pandemics as "disasters." This would enable national and local governments to respond more appropriately to pandemics. Although both types of government have the authority to mobilize resources in disasters even from the private sector, the relevant mechanisms cannot be exercised in the context of COVID-19 pandemic, which is not legally defined as a disaster. In the absence of this, management is based on laws that are related to infectious disease control, which give governments the power to make strong requests at most, even after the recent amendment strengthening gubernatorial power. In addition, without full activation of disaster responses, inter-jurisdiction collaboration mechanisms, particularly wide-area patient transfer across prefectural or municipal borders, would not function appropriately. An all-hazards approach would be

preferable, such that we can prepare for and respond to all kinds of public health emergencies under the disaster management framework (22).

As mentioned throughout the paper, Japan must designate clear entry points to the healthcare system, with established gatekeeper roles. At the very least, this should be done during public health emergencies, especially in cases with surging numbers of patients. We must absolutely alter the current approach to emergency medical services, in which ambulance crews are tasked with searching for entry points (13–15). Given that medical resources are dispersed across a large number of small- and medium-sized hospitals, there are significant variations in the abilities of individual emergency departments. This highlights the need for a system in which an initial treatment center is available for emergency patients, specifically to accept all patients from a geographically defined area, then redistribute them to appropriate hospitals based on both their own medical conditions and the abilities of the intended facility. This will also facilitate daily operations in general. Even before the pandemic, there were several cases in which ambulance teams had difficulty finding hospitals for their patients. While issues must be addressed in both situations, it is better to overcrowd emergency departments than force ambulances to park throughout the communities.

Accurate quantification of the existing healthcare resources is crucial, especially for use in public health emergencies. However, current figures do not accurately indicate the number of beds available for acute care due to the insufficient differentiation of bed functions in Japan. The Ministry of Health, Labour and Welfare has initiated a system for reporting bed functions to help facilitate this issue, but it is also necessary to reflect differentiations in the official statistics, thus more precisely indicating what resources are available during times of disaster. To obtain information on the available resources in real-time, further utilization of information technology is desirable. Although the Ministry of Health, Labour and Welfare operates a system to collect medical resource information from hospitals throughout the country, its requirement of human data inputting makes collecting information in real-time impossible. A more sophisticated system that can automatically collect information (e.g., using artificial intelligence) would expedite information sharing about available resources (artificial intelligence may also be useful in predicting resource needs). In addition, information sharing mechanisms may also promote local or regional coordination (23).

Finally, we may need to reconsider Japan's regulatory and efficiency-oriented policies to overly streamline its healthcare resources. Seemingly, Japan's current medical resources are insufficient to deal with a public health emergency while continuing regular services reflecting previous efficiency policies to cut the resources to the minimum to maintain regular services. In addition, flexibly increasing hospital beds is not legally allowed. The Ministry of Health, Labour and Welfare has planned to further cut acute care beds with low utilization by reorganizing acute care public hospitals (24). However, in case of emergencies, further resource cuts may need to be reconsidered (to create resource surplus in ordinary times, if not excessive) and flexibility should be introduced to rapidly increase temporary beds.

CONCLUSIONS

Japan's healthcare system has not been able to sufficiently or promptly address a rapid increase in the number of patients who require hospitalization due to COVID-19. Contributing factors include the dispersed nature of existing medical resources, the lack of collaboration mechanisms among private-dominant healthcare providers and public health agencies, an inadequate legal framework for responding to all kinds of emergencies, the insufficient quantification of existing resources, and a lack of designated entry points to healthcare systems. To address these issues and prepare for the next wave of COVID-19 and any future disasters, Japan urgently needs to restructure its legal framework to promptly mobilize resources, accurately quantify existing resources, introduce coordination mechanisms with functional differentiations among all community stakeholders, and clearly designate entry points to healthcare.

DATA AVAILABILITY STATEMENT

The datasets used for this study can be found (8, 10, 16).

AUTHOR CONTRIBUTIONS

SN conceived the idea of the paper and drafted the manuscript. HI, MI, and JT contributed to revising the manuscript. All authors approved the final version.

FUNDING

This work was supported by JSPS KAKENHI (No. 18K09967) and the Health, Labour and Welfare Policy Research Grants Research on Health Security Control (No. 19LA2003).

ACKNOWLEDGMENTS

We thank Editage for English language editing.

REFERENCES

1. Unruh L, Allin S, Marchildon G, Burke S, Barry S, Siersbaek R, et al. A comparison of 2020 health policy responses to the COVID-19 pandemic in Canada, Ireland, the United Kingdom and the United States of America. *Health Policy*. (2021) (in press). doi: 10.1016/j.healthpol.2021.06.012
2. Barnett DJ, Knieser L, Errett NA, Rosenblum AJ, Seshamani M, Kirsch TD. Reexamining health care coalitions in light of COVID-19. *Disaster Med Public Health Prep*. (2020) (in press). doi: 10.1017/dmp.2020.431
3. Devereaux A, Yang H, Seda G, Sankar V, Maves RC, Karanjia N, et al. Optimizing scarce resource allocation during COVID-19: rapid creation of a regional health-care coalition and triage teams in San

Diego county, California. *Disaster Med Public Health Prep*. (2020) (in press). doi: 10.1017/dmp.2020.344
4. Tsukimori O. The hospital conundrum: why Tokyo's health system is overflowing with COVID-19 patients. *The Japan Times*. (2021). Available online at: https://www.japantimes.co.jp/news/2021/09/14/national/hospital-system-tokyo-coronavirus/ (accessed September 30, 2021).
5. Tokyo Metropolitan Government. *Updates on COVID-19 in Tokyo*. (2021). Available online at: https://stopcovid19.metro.tokyo.lg.jp/en (accessed September 30, 2021).
6. Ikegami N, Yoo B-K, Hashimoto H, Matsumoto M, Ogata H, Babazono A, et al. Japanese universal health coverage: evolution, achievements, and challenges. *Lancet*. (2011) 378:1106–15. doi: 10.1016/S0140-6736(11)60828-3
7. Hashimoto H, Ikegami N, Shibuya K, Izumida N, Noguchi H, Yasunaga H, et al. Cost containment and quality of care in Japan: is there a trade-off? *Lancet*. (2011) 378:1174–82. doi: 10.1016/S0140-6736(11)60987-2
8. Organization for Economic Cooperation and Development. *Health Care Resources*. (2021). Available online at: https://doi.org/10.1787/health-data-en (accessed September 30, 2021).
9. Ritchie H, Ortiz-Ospina E, Beltekian D, Mathieu E, Hasell J, Macdonald B, et al. *Coronavirus Pandemic (COVID-19). Our World in Data*. (2020). Available online at: https://ourworldindata.org/coronavirus (accessed September 30, 2021).
10. Ministry of Health, Labour and Welfare. *Survey on the Medical Care and the Number of Inpatient Beds for COVID-19 Patients 16 September 2021*. (2021). Available online at: https://www.mhlw.go.jp/stf/seisakunitsuite/newpage_00023.html (accessed September 30, 2021).
11. Sakamoto H, Rahman M, Nomura S, Okamoto E, Koike S, Yasunaga H, et al. *Japan Health System Review: World Health Organization*. New Delhi: Regional Office for South-East Asia (2018).
12. Ito K, Sou Y, Koizumi G, Kanda J, Miyake Y, Sakamoto T, et al. Infection control strategy using a hybrid resuscitation room system during the COVID-19 pandemic in Tokyo, Japan. *Ann Emerg Med*. (2020) 76:816–7. doi: 10.1016/j.annemergmed.2020.06.052
13. Nakahara S, Kanda J, Miyake Y, Sakamoto T. High incidence of heat illness and the potential burden on the health care system during the COVID-19 pandemic. *Lancet Reg Health West Pac*. (2021) 6:100070. doi: 10.1016/j.lanwpc.2020.100070
14. Long ambulance waits now the norm for cases of COVID-19. *The Asahi Shimbun*. (2021). Available online at: https://www.asahi.com/ajw/articles/14422783 (accessed September 30, 2021).
15. Tokyo COVID-19 patients unable to access hospitals as cases remain high. *The Japan Times*. (2021). Available online at: https://www.japantimes.co.jp/news/2021/08/20/national/tokyo-covid-19-patients-hospital-access/ (accessed September 30, 2021).
16. Ministry of Health, Labour and Welfare. *Medical facility survey 2019*. Tokyo: The Ministry (2020). Available online at: https://www.e-stat.go.jp/stat-search/files?page=1&toukei=00450021&tstat=000001030908
17. Ministry of Health, Labour and Welfare. *Capacities to Treat COVID-19 Patients by Type and Size of Medical Facilities*. Tokyo: The Ministry (2021). Available online at: https://www.mhlw.go.jp/content/10800000/000726034.pdf (accessed September 30, 2021).
18. Yamamoto T, Ozaki M, Kasugai D, Burnham G. Assessment of critical care surge capacity during the COVID-19 pandemic in Japan. *Health Secur*. (2021) 19:479–87. doi: 10.1089/hs.2020.0227
19. Cabinet Office. *Disaster Management in Japan 2021*. Tokyo: The Office (2021). Available online at: http://www.bousai.go.jp/1info/pdf/saigaipamphlet_je.pdf (accessed September 30, 2021).
20. Minato Disaster Medical Care System Study Group. Bottom-up approach to establish coordination mechanisms for disaster preparedness among largely private healthcare providers in central Tokyo. *Disaster Med Public Health Prep*. (2021) (in press). doi: 10.1017/dmp.2021.326
21. Osaki T. Japan's health care system teeters on the brink as coronavirus takes a toll on hospitals. *The Japan Times*. (2020). Available online at: https://www.japantimes.co.jp/news/2020/04/29/national/japans-health-care-system-teeters-brink-coronavirus-takes-toll-hospitals/ (accessed September 30, 2021).
22. Barbera JA, MacIntyre A, editors. *Medical Surge Capacity and Capability: The Healthcare Coalition in Emergency Response and Recovery*. Washington DC: U.S. Department of Health and Human Services (2009).
23. Noguchi H. Preparing for the 6th wave of COVID-19: importance of coordination among stakeholders in ordinary times. *Nikkei Shimbun*. (2021). Available online at: https://www.nikkei.com/article/DGKKZO78010620Q1A131C2KE8000/ (accessed December 1, 2021).
24. Director General, Medical Affairs Bureau, Ministry of Health, Labour and Welfare. *Re-Examination of Specific Policies Regarding the Future Role and Size of Public Medical Institutions. Notice No. 0117-4*. Tokyo: The Ministry (2021). Available online at: https://www.mhlw.go.jp/content/10802000/000585491.pdf (accessed December 1, 2021).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Psychology

ORIGINAL RESEARCH
published: 16 February 2022
doi: 10.3389/fpsyg.2022.747967

The Tendency of Terrorist Organizations to Explosive Attacks: An Institutional Theory Perspective

*Lanjun Luo and Chao Qi**

School of Management, Huazhong University of Science and Technology, Wuhan, China

Focusing on the tendency of terrorist organizations to explosive attack, this article applied the institutional theory as the basis to explain the inherent logic of attack type similarity from the perspective of mimetic, coercive, and normative isomorphism. Subsequently, the study conducted an empirical analysis of the data onto 1825 terrorist organizations recorded in the Global Terrorism Database with the logistic regression method. The results show that: (1) Terrorist organizations will learn from pre-existing terrorist organizations' experiences, and mimetic isomorphism will promote explosive tendency; (2) Due to the normative isomorphism effect, terrorist groups' tendency to explosive attacks is weakened by their increased duration; (3) If terrorist organizations are hostile to a strong government, coercive isomorphism positively moderates the negative effects of increasing duration. The study suggests that counter-terrorism approaches such as destroying the learnable experience of attacks, addressing the root causes of terrorism, and maintaining a strong government may be helpful in stopping increasing terrorist activities, which is essential for reducing terrorist organizations' vivosphere, blocking the inter-flow and imitation between terrorist organizations, and ultimately interrupting the terrorist propagation chain.

Keywords: explosive attack, institutional theory, organizational isomorphism, terrorist organization behavior, terrorism contagious

OPEN ACCESS

Edited by:
Jarle Løwe Sørensen, University of South-Eastern Norway, Norway

Reviewed by:
Eduardo Moraes Sarmento, Lusophone University of Humanities and Technologies, Portugal
Umer Shahzad, Anhui University of Finance and Economics, China
Glenn Diesen, University of South-Eastern Norway, Norway

***Correspondence:**
Chao Qi
qichao@hust.edu.cn

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *27 July 2021*
Accepted: *21 January 2022*
Published: *16 February 2022*

Citation:
Luo L and Qi C (2022) The Tendency of Terrorist Organizations to Explosive Attacks: An Institutional Theory Perspective. Front. Psychol. 13:747967. doi: 10.3389/fpsyg.2022.747967

1. INTRODUCTION

After 9/11, counter-terrorism (CT) became a priority for homeland security worldwide, and enormous amounts of material and human resources are cost in this area. However, many intelligence-led CT and prevention approaches, regarded as pre-emptive and precision strikes, have not achieved the desired results but instead have added fuel to the fire (Bjørgo, 2013). As shown in **Figure 1**, the frequency of terrorist attacks worldwide, as recorded in the Global Terrorism Database (GTD) (LaFree and Dugan, 2007; START, 2021), is still on an upward trajectory. This unexpected trend means that CT operations have not stopped the actions of terrorists and terrorist organizations, the adversarial strategies still have not entirely grasped the behavioral patterns of enemies. Therefore, to make CT more effective, a better understanding of the behavioral patterns of terrorist organizations and the underlying causes is necessary.

One of the most critical aspects of terrorist organization behavior patterns is the attack type. As shown in **Figure 1**, the explosive attack is the most used type worldwide each year. This article has also counted the attack types of 181,691 cases in GTD, and the results are shown in **Table 1**. The most frequent attack type is still bombing and explosion, with 88,255 records and accounting for

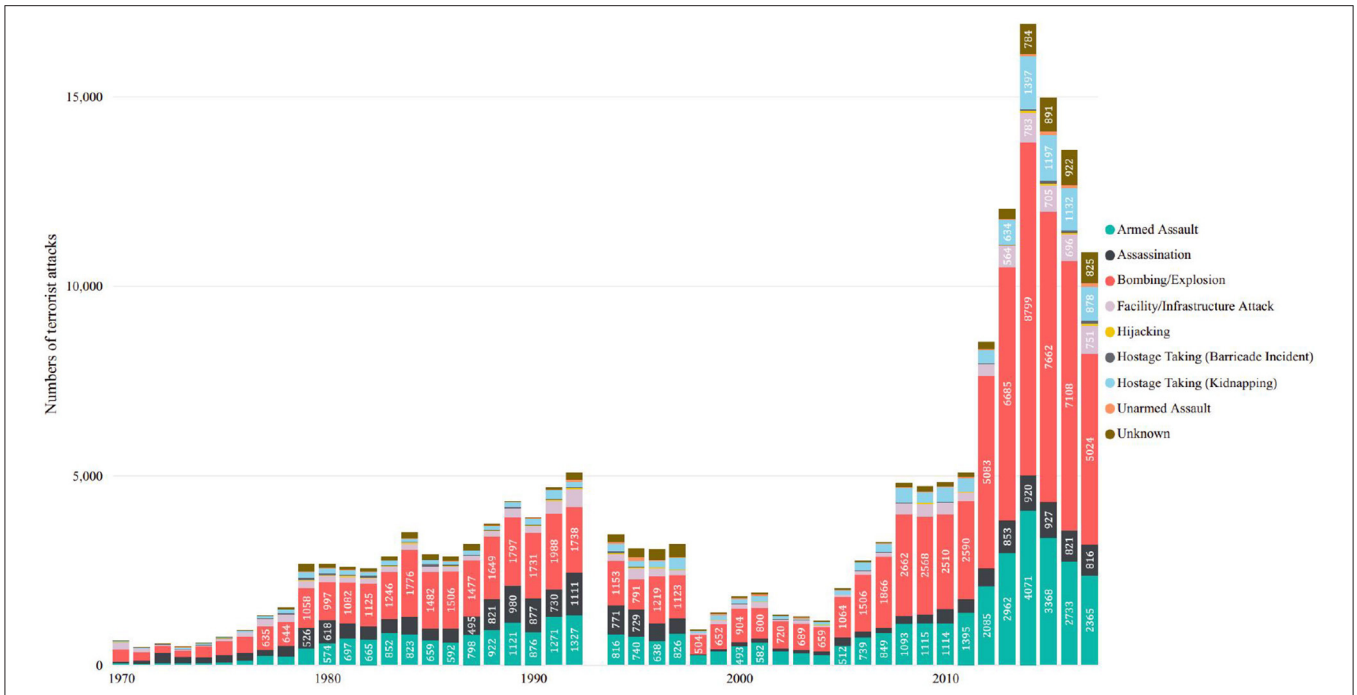


FIGURE 1 | Global terrorism trend and proportion of different attack types (Data source: GTD, 1970-2017, attack type statistics using GTD's variable *attacktype*1_*txt*).

TABLE 1 | The number of different attack types in GTD (Data source: GTD, 1970-2017, attack type statistics using GTD's variable *attacktype*1_*txt*).

Method of terrorist attacks	Number of cases
Bombing/Explosion	88,255
Armed assault	42,669
Assassination	19,312
Hostage taking (Kidnapping)	11,158
Facility/Infrastructure attack	10,356
Unknown	7,276
Unarmed assault	1,015
Hijacking	991
Hostage taking (Barricade incident)	659

48.57% of the total, far more than any other terrorist attack category. Moreover, different terrorist organizations also demonstrate a tendency to commit explosive attacks. **Figure 2** illustrates an analysis of the attack types of several notorious terrorist organizations. It can be seen, these terrorist organizations have shown a focus on explosive attacks, e.g., both the Taliban and the Islamic State of Iraq and the Levant (ISIL) use explosions as the most common method. For organizations such as the Farabundo Martí National Liberation Front (FMLN), explosive attacks, while not the most frequent, are still among the most common.

Why do terrorist organizations have a similar behavior pattern that tends to explosive attacks? To our knowledge, few studies directly answer this question, but some of them address other aspects of terrorist organization similarity. Representative, Di Salvatore (2018) found pirates similarly tend to cluster in places where successful attacks have occurred. Parker and Sitter (2016) found terrorist organizations with similar ideologies were similar in tactics, strategies, and objectives. Both pieces of research regard the similarity of terrorists' behavior patterns as mainly a result of inter-organization learning and imitating process, while the latter keenly recognized the process is analogous to the isomorphism of enterprise organizations analyzed by institutional theory (DiMaggio and Powell, 1983) in sociology.

However, the existing approaches are not sufficient to explain the explosive tendency. Firstly, in terms of explosive attacks, the objects of different terrorist organizations imitating and learning from are unclear. Most terrorist organizations mainly operate in a limited area or within a relatively fixed range. For example, Abu Sayyaf primarily operates in Chechnya and Laskhar Jihad in Indonesia (Ganor, 2008). Even for transnational or international terrorist organizations, the preparation and requirements for launching explosive attacks in different countries are heterogeneous. How do terrorist organizations in different areas choose the imitation targets and learn from them? Secondly, the formation of similar behavioral patterns in terrorist organizations is not only free will-led learning results but may be shaped by complicated conditions and environments. In Western or well-policed societies terrorists are heavily repressed, and less restricted in lawless areas (Ganor, 2008). Terrorists are not at liberty to learn from others' experiences and practice them. CT forces are constantly trying various military, political, and economic methods to forge an "iron cage" in the hope of hanging them. How does external coercion shape the similarity of terrorist organizations? Thirdly, if terrorist organizations can

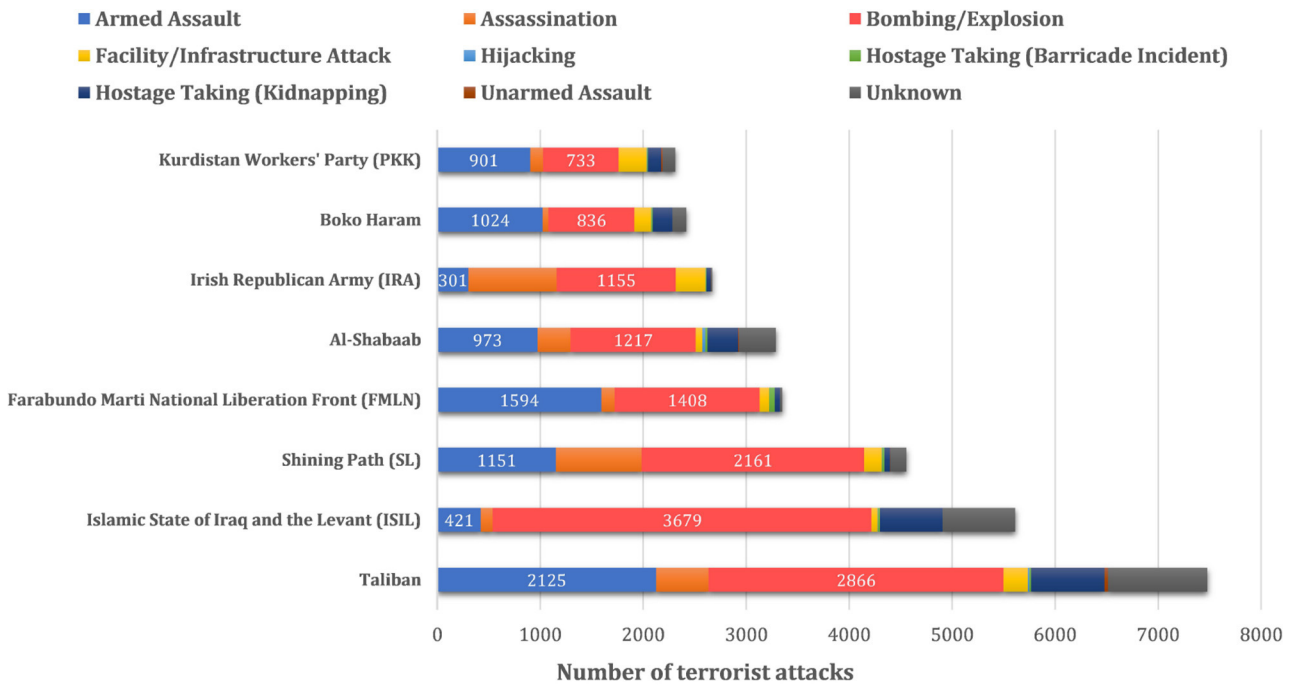


FIGURE 2 | Comparison of several terrorist organizations' attack methods (Data source: GTD, 1970–2017, the total attack number of a specific terrorist organization is calculated by the times recorded in GTD's variable *gname*, while the attack types statistics by *attacktype*1_*txt*).

survive under coercion for a longer time, then it seems they can choose other more destructive and specialized attacks to fulfill their political or social goals. For example, plane hijackings always create serious media attention and chaos (Terrorism-Research.com, 2021). How do the increasing professionalization and operational capacity represented by a terrorist organization's persistence affect organizational similarity?

The complete institutional theory may help answer the above questions, analyzing how multiple driving forces shape organizational similarities is its core (DiMaggio and Powell, 1983). The organizations' isomorphism phenomenon, which manifested in the resemble of different organizations, is caused by three types of isomorphism: mimetic isomorphism due to dealing with uncertainty, coercive isomorphism driven by legal or political pressure, and normative isomorphism due to professional experts and organizations (DiMaggio and Powell, 1983; Hersberger-Langloh et al., 2021). Early institutional theory studies have focused primarily on the isomorphism of typical organizational forms and practices (Ufere et al., 2020). Recently, more research has paid attention to illegal behaviors, e.g., the bribery pervasive among firms (Ufere et al., 2020), and the criminogenic isomorphism in the business context (Glebovskiy, 2019). There are also studies that apply institution theory to the public safety issues, such as the widely social media adopting of police departments (Hu et al., 2018), and the similarities in investigating human trafficking law enforcement efforts (Warren, 2019).

The three isomorphic processes in institutional theory have focused on the causes and targets of organizational learning, the influence of external pressures, and the impact of professionalization. Such findings may help us understand the learning reason and objects of terrorist organizations, the effects of CT pressures, and the influence of capability and specialization represented by the age of the organization. Nevertheless, many internal isomorphism mechanisms are still puzzling, and the relevant studies of institutional theory have not delved into the issue of terrorist organization behavioral isomorphism, especially the empirical research on the tendency to explosive attacks is still a gap.

Therefore, this study attempts to develop a conceptual model to explain the terrorist organizations' explosive attack tendency from the perspective of institutional theory, and to analyze the behavioral similarity of terrorist organizations based on the three drivers in institutional theory—coercive, normative, and mimetic isomorphism. In particular, we aim to answer the following three research questions in an extension of existing terrorism researches and institutional theory studies:

- How do terrorist organizations mimic explosive attack experiences, and who are the learning targets?
- How does the increase of the terrorist organizations' persistence affect their explosive attack tendency?
- How do CT pressures shape terrorist organizations' explosive tendency?

The contributions of this article are mainly threefold. Firstly, we apply institutional theory to the analysis on the illegal behavioral isomorphism of terrorist organizations; previous studies have mainly been limited to legal organizations' legal or

illegal behavior, which facilitates the application of institutional theory. Second, based on the institutional theory's mimetic isomorphic drive, we analyze the possible targets for terrorist organizations to learn from the experience of bombing attacks cross-organisationally. Thirdly, based on normative and coercive isomorphism, the difference in approach between terrorist organizations and ordinary business organizations in the face of institutional iron cages is analyzed, and short- and long-term combined CT policy recommendations are given.

The rest of this study is structured as follows. In section 2, we review the related studies. The main hypotheses of this study are presented in section 3. Section 4 explains the variable selection and data obtaining methods. Logistic regression results are in section 5. In section 6, we discussed this study's management implications and limitations. Finally, the research is concluded in section 7.

2. LITERATURE REVIEW

This section first reviews the common organizational isomorphism phenomenons in the institutional theory researches and how the three structures of uncertainty-mimetic isomorphism, professional-normative isomorphism, and formal pressure-coercion isomorphism come into play. Second, we introduced other alternative terrorist attack types and the differences with explosive attacks. Third, the related institutional environments and root causes of terrorism are reviewed.

2.1. Institutional Theory and Its Applications

Institution, defined as "regulative, normative, and cognitive structures and activities that provide stability and meaning for social behavior" (Scott and others, 1995). As a crucial part of the whole environment, institutions include laws, social and professional norms, culture, ethics, etc. (Miles, 2012). The institutional theory studies mainly focus on how the organizations evolve toward similarity in the institutional environment. The three isomorphic mechanisms proposed (DiMaggio and Powell, 1983) have become the mainstream tools of this research field.

Existing institutional theory researches can be divided into three categories depending on the research objectives. First, the most orthodox and mainstream application of institutional theory is to explain legitimate business organizations' legal behavior and structural isomorphism. Davis et al. (2000) applied the institutional theory framework to analyze the international entry mode of strategic business units. Brouthers et al. (2005) theorized that emerging market firms can improve export performance satisfaction by imitating the modal generic product strategy from the home country multi-national enterprises. Marquis et al. (2007) found the institutional pressures at the community level can make corporate overcome immediate profit maximization goals and focus more on social benefits and issues. Zach et al. (2021) found determinants such as alliance membership and firm size play an important role in innovation copying, an inter-firm mimetic isomorphism phenomenon.

Second, some studies focus on the non-legitimate behavior isomorphism of legitimate business organizations. Venard (2009) found competitive and institutional isomorphism have a crucial influence on the corruption in Russia firms. Among the three isomorphic drives, the normative isomorphism (imitation to competing firms) and the mimetic isomorphism (ethical behavior brought by multi-nationals) both have a significant effect on corrupt behavior in Russian firms, while the coercive isomorphism (quality of the legal framework, law, and financial markets) was shown not applicable. Gao (2010) found that the mimetic isomorphism motivated by other firms' bribing behavior significantly affects the bribery of firms in transitional China. Ufere et al. (2020) found the mimetic isomorphism (perception of frequently bribery practices in specific industries) and the coercive isomorphism (institutional constraints on businesses) have positive relationships with bribery pervasive among sub-Saharan African firms.

In addition, police organization behavior and structure isomorphism is also a theme. Giblin (2006) proofed the institutional factor—accreditation, can represent both normative and coercive pressure, while increases the isomorphism odds of the crime analysis unit incorporation in police organizations. Soeters (2008) found common experiences and inter-military learning shape the operation isomorphism of American and Netherlands armed forces in Afghanistan. Obviously, mimetic isomorphism played an important role. Dupont (2015) assessed the limitations of CT forces to generate an adversarial isomorphic network structure against terrorists. This comes from the observation that new terrorists are similar in building a structure of decentralized distributed networks, thus gaining more ability to sustain CT strikes. Burruss and Giblin (2014) applied institutional theory to analysis the similar adoption of community policing in municipal law enforcement agencies. They found centrist forces, e.g., professionalization of law enforcement, are the driver of the community policing isomorphism. Carter (2016) found the institutional pressures have a significant positive effect on the adoption of intelligence-led policing.

In general, institutional theory has been well applied to explain the isomorphism of legal and illegal behavior in various kinds of legitimate organizations. Existing researches also help us understand how the three isomorphic processes operate. The research on illegal behavior and policing organizations' similarities lead us to believe that this theory can also be applied to the isomorphism of terrorist organizations. However, the analysis of the co-occurrence of illegal organizations and illegal behaviors remains missing in the existing studies.

2.2. Terrorism, Explosive Attack, and Alternative Types

When the common tendency of terrorist organizations to explosive attacks is found, it is necessary first to review what terrorism is and what other attack types besides bombing are available.

Terrorism, as a complex aggregate of concepts and phenomena, is still difficult to define in a thoroughly uniform

single manner (McCann and Pimley, 2020). The relatively commonly accepted definition is that terrorism is an act of a political, violent, radical nature involving non-state actors with the intention of spreading a broader psychological fear effect (Byman, 2020). As shown in **Table 1**, except for the explosive and bombing attack, there are seven alternative attack types: assassination, armed assault, hijacking, two kinds of hostage-taking, facility and infrastructure attack, and unarmed assault. The difference between these methods and explosive attacks needs to be clarified. All the eight types can be divided into three categories according to their objects: against human objects, against material objects, and hybrid.

In GTD, The armed assault attacks aim to cause harm or death to human beings with firearms or other lethal instruments, e.g., the attack against Shia prisoners in June 2014 (Sly and Ramadan, 2014; START, 2021). In comparison, the unarmed assault attacks want to achieve the same goal by using other means, including biological, chemical, and radiological, e.g., the chemical-related incident in Uganda in March 2000 (Cirjak Antonia, 2020; START, 2021). Further, hostage-taking (two kinds) and assassination are apparent human targeted attacks. Unlike the first category, the hijacking with the primary object of taking control of vehicles and the facility-infrastructure aimed are both attacks against material objects. The representative case for the former type is the "9/11" attack, and the latter is the bus attack in Angola in August 2001 (Guardian, 2001; START, 2021).

Unlike other types, explosive attacks' objects are hybrid. Both people and materials can be the targets. For example, the coordinated vehicle explosive attacks in Iraq in August 2007 set the first target on minority people while also destroying villages (START, 2021). In addition to the difference in target, the major difference between explosive and other methods is that bombings are relatively cheap and easy to make and are smaller, harder to detect, and often highly damaging (Terrorism-Research.com, 2021). And Parker and Sitter (2016) also thought the advances in weapon affordability, portability, and concealability gave terrorists a "force multiplier." Compared with other methods such as kidnapping, which is regarded as "one of the most difficult acts" (Terrorism-Research.com, 2021), explosive seems to serve the needs of terrorists better.

However, although explosives have some advantages in launching attacks, the occurrence of specific attacks is the result of the multiple-coupling conditions and is not entirely the weapon power factors' consequence such as convenience, cheapness, and concealability. In the view of situational crime prevention research, the target constitutes one of the most crucial aspects besides weapon selection (Clarke and Newman, 2006; Hsu and Newman, 2016). Elements such as the target's exposure, vitality, destructibility, and iconicity trigger specific terrorist attacks (Clarke and Newman, 2006). Then, if a terrorist group's experience is all against unarmed or weakly defended targets, perhaps it would hardly be a learning destination for terrorist organizations operating against powerful even military targets. At the same time, the degree of defense is often related to various political, military, and economic factors in the institutional environment where the target is located. Therefore, it is necessary to consider broader environments and examine who the different terrorist organizations can effectively learn from.

2.3. The Institutional Environment of Terrorist Organizations

The institutional environments at the country level are usually composed of both formal and informal institutions (Hitt, 2016). This is true for business organizations, and it is also valid for illegal organizations. For firms, the traditional institutions are represented by laws and standards (Scott and others, 1995), and the informal institutions is represented by culture (Fu et al., 2004). For terrorist organizations, the institutional environment is most likely the root cause of terrorism.

Terrorism originates in wide economic, political, and conflict backgrounds, many root cause analyses are exploring "what breeds terrorism" (Kis-Katos et al., 2011). These root causes collectively form the most important part of the institutional environment where terrorist organizations exist. Typically, for economic causes, Krieger and Meierrieks (2019) found that the higher income inequality level caused worse institutional corruption and more domestic terrorist activity. Ajide and Alimi (2021) found income inequality, human capital, and educational attainment have impact on terrorism. Bagchi and Paul (2018) found youth unemployment tends to increase domestic terrorism while may not effect the transnational terrorism. Gassebner and Luechinger (2011) found factors such as GDP, population, and economic freedom have significant impact on terrorism. For political causes, Ajide et al. (2020) found natural resource rents, political regimes (democracy and autocracy) both have effects on terrorism. Baek and Bouzinov (2021) found the increasing effect of democratization on terrorism reaches peak when a country is at very middle democracy level. For conflict, Schumacher and Schraeder (2021) found the domestic political instability (government purges and riots) increase terrorism. Shahzad et al. (2020) found foreign aid fuels terrorism because of the institutional problems and civil conflicts. Gassebner and Luechinger (2011) also investigated the influences on terrorism from guerrilla war, internal war, ethnic tensions, and other conflict factors.

Meanwhile, just as businesses are not prisoners of their institutional environments, but may act in creative ways to change their institutional environments (Dimaggio, 1988), terrorist organizations are in turn influencing theirs. Inspiring, Zulfiqar et al. (2014) found terrorism negatively influenced the foreign direct investment in Pakistan. Shahzad et al. (2019) found terrorism increased the capital flight. Lanouar and Shahzad (2021) found terrorist attacks in big cities can cause the highest negative impact on the capital flow. Evidence of increased capital flight due to terrorist attacks is also further confirmed in the study of Shahzad and Qin (2019). Through the above research, it is clear to see how terrorist organizations and terrorist attacks inversely act on the institutional environment.

Moreover, along with other formal coercive powers, CT activities are also an important part of constructing the institutional environment for terrorist organizations. At the macro level, Shahzad and Qin (2019) found military expenditures

can decrease the impact of terrorism on the capital flight. Shahzad et al. (2019) also thought military expenditures, counter terrorism policies, stable political environment, and better economy contribute to the containment effect of curbing the negative effects of terrorism. At the micro level, Di Salvatore (2018) found that for pirates who like to cluster in previous successful locations to repeat their attacks, rescue operations can reduce most attacks in the following month. The similar control benefit diffusion effects may be valid for other terrorist attack types (Hsu and Newman, 2016).

In conclusion, the above reviews reveal the dialectical relationship between terrorist organizations and their institutional environment. In the next section, we will explore how institutions make terrorist organizations become similar in the attack type and how terrorist organizations break the institutional iron cage.

3. RESEARCH HYPOTHESES

3.1. Mimetic Isomorphism: Limited Imitation Objects

Uncertainty is one of the most critical forces that cause mimetic isomorphism (DiMaggio and Powell, 1983; Miles, 2012). Uncertainty means that the organization does not know what to do because, e.g., ambiguous goals and uncertainty about appropriate behavior (Miles, 2012; Deligonul et al., 2013). Thus, Organizations like firms tend to imitate the successful behavior of others in the same organizational field (Ufere et al., 2020). Although Parker and Sitter (2016) found that the behavior of early terrorists may provide ideological and tactical inspiration for the later ones. However, in terms of specific terrorist organizations wishing to learn the experience of explosive attacks, it remains unclear who these prior organizations were.

The two crucial points—uncertainty and organizational domain—help to answer the question of learning objects. Researches have demonstrated how the root causes of terrorism interact with terrorist attacks at the country level (Gassebner and Luechinger, 2011). The countries that terrorist organizations confront often constitute the most representative organizational field. Terrorist organizations in the same country with similar primary operating areas will most often face similar pressures from CT actions, political penalties, economic sanctions, etc. For example, in Iraq, during the period of US-led coalition intervention, improvised explosive device attacks are always likely leading to similar clustered counter-insurgency activities (Braithwaite and Johnson, 2012). The same organizational field, which is destructive and uncertain to terrorist attacks, has effected not only pre-existing terrorist organizations, but also subsequently arising terrorist organizations. The most immediate response of the newcomers to this pressure is to learn from the experience of other pre-existing terrorist organizations in the same organizational domain, namely the same country. Although it is possible to learn terrorist attack experience through the Internet, the actual bomb-making, target investigation, and other techniques in specific contexts, terrorists can only gain the most intuitive experience by learning in the real world (Bruce, 2009; Kenney, 2009). Rather than learning from other terrorist groups' bombing experiences in countries with different institutional environments, it may be better for a terrorist organization to learn from the behavior of existing groups in the same specific country. In other words, terrorist organizations imitate a limited range of objects, most probably organizations that operate mainly in the same countries. The explosive tendency and experience of existing terrorist organizations will greatly influence the latter's behavior. Thus:

H1: Pre-existing terrorist organizations' tendency to explosive attacks may have a positive impact on the tendency of later groups in the same country.

3.2. Normative Isomorphism: Professionalization and the Asthenia of Iron Cage

In institutional theory, normative isomorphism is primarily caused by professionalization (DiMaggio and Powell, 1983), standards, employee movement (Miles, 2012), etc. In turn, business organizations become similar under these specialized forces. However, different from firms, the professionalization may fuel terrorist organizations to break the institutional iron cage, rather than conform.

Facing external threats, terrorist organizations often cooperate and train attack experts with each other in order to strengthen themselves and keep their organizations alive (Phillips, 2014). This inter-organizational circulation of personnel points to the professionalization of modern terrorist organizations. Similar to organized criminal groups (Sanderson, 2004), personnel training, equipping, recruiting, transporting, and intelligence acquisition all form part of the normalization and specialization requirements of terrorist organizations. Thus, if a terrorist organization persists for an extended period, it usually accumulates a pool of terrorists with multiple attack capabilities, which potentially strengthens its bargaining power against governments as well.

The longer a terrorist organization lasts, meaning the more the iron cage holding it collapses, the more bargaining power it has, and it may no longer stick to explosive attacks but will consider more alternative approaches. At this time terrorist organizations may be thinking about getting more results, such as terror and disruption. Because of increased professionalization, the attack type is no longer confined to explosions, the affordability, portability, and concealability of weapons are no longer crucial. Thus:

H2: The longer duration of a terrorist organization has a negative impact on the explosive attack tendency.

3.3. Coercive Isomorphism: Reinforcement of the Iron Cage

Although the professionalization and persistence may enhance the capabilities of terrorist organizations, the forces of CT are perpetually reinforcing the coercive iron cage. In business contexts, the formation of coercive isomorphism is the result of an explicit regulatory process: rule-making, monitoring,

and sanctioning activities. Both government rules and forces from culture and society can impose standards on business organizations. For organizations in the organizational field, failure to conform to institutional expectations can have profound implications for the organization's legitimacy, ultimately leading to loss of tax-exempt status, loss of grants and contracts, or involuntary dissolution. Under the pressure of legitimacy and specific circumstances, business organizations may choose to operate primarily for legitimacy rather than for-profit.

In terrorism and CT contexts, such a process of coercive isomorphism is not directly applicable to terrorist organizations. The traditional binary relationship between government and business is challenging to apply to "autonomous" (Helfstein, 2009) organizations such as terrorist organizations. The claims of legitimacy of business organizations do not coincide with the claims of terrorist organizations. Nevertheless, this does not mean that the institutional theory fails to explain the isomorphism of terrorist organizations' behavior in the dimension of coercive isomorphism. The demands of terrorist organizations are more political than economic (Jongman, 2005). As far as legitimacy is concerned, referring to the work of Zarakol (2011), this article argues that the "legitimacy" of a terrorist organization is more likely to come from (a) Recognition by peer organizations, internal members; (b) The support of backers, potential militants; (c) The relative stability of political claims. If the government-business organization represents a healthy and mutually beneficial relationship, the government-terrorist organization relationship is characterized by hostility and unilateral sanctions.

The formation of terrorist organizations comes from the root cause of terrorism, which usually includes formal support from anti-government, anti-social forces, and deep-seated informal contradictions in society, culture, economy, and politics. As a group with political agenda, terrorist organizations usually aim to change the power base of a target state, thus creating a hostile binary relationship with the government. However, in the face of the government, the representative of the state's authority, terrorist groups have a dangerous role to play in the war on terror, especially when the government is relatively strong. In this case, it is bound to face a "legitimacy crisis" That is to say, in such a relationship, the terrorist organization is subjected to coercive sanctions that are far more powerful than those imposed on ordinary businesses, no longer bound by laws or rules but by military and police forces.

When terrorist organizations operate primarily in regions where the countries are stable and powerful, they are always subject to more stringent repressive responses. Sovereign governments and the corresponding authorities have always been able to respond promptly, for example, by intervening immediately when attacks or hotspots of attacks occur and by adopting long-term and proactive prevention strategies to address root causes of terrorism further. In this scenario, terrorist organizations would gradually weaken while losing some survival space. As criminals with less bargaining power, terrorist organizations will choose the most logical way to respond to sanctions, and the low-cost, more lethal, and easier-to-use bombings are common to terrorist organizations than other attacks that require sophisticated planning, surveillance, and staffing. Moreover, in situations where governments are weak or even disintegrating, as in Iraq and Afghanistan, terrorist groups often have more bargaining power due to the growth of anti-government forces. In such cases, hostage-taking, aircraft hijacking, and other terrorist attack methods may bring more economic and political gains, and bombing attacks may no longer be their favorite option.

Therefore, the effect of duration is not absolute, and when the government is stable, even long-dormant terrorist groups can hardly have forces hostage to bargaining with the government. Thus, this article proposes the following moderating effect:

> **H3**: The negative effect of duration is attenuated when terrorist organizations carry out terrorist attacks mainly in regions with strong governments, which means there is a positive moderating effect.

In summary, the conceptual explanatory model of the tendency of terrorist organizations to explosive attacks from the perspective of an institutional theory constructed in this article is shown in **Figure 3**.

4. MATERIALS AND METHODS

4.1. Data Sources

The data used in this study are from the GTD database. GTD is currently one of the most complete databases of terrorist attacks globally, mainly collected and maintained by the National Consortium for the Study of Terrorism and Responses to Terrorism (START) in the United States (START, 2021). Till the end of 2017, GTD has collected more than 180,000 terrorist attacks in 12 regions of more than 200 countries over half a century, and all the incidents are indexed with variable "eventID." About 98,000 cases with specific terrorist organizations have been identified among all records, and more than 3,500 terrorist organizations have been recorded. In addition, the GTD records detailed information about the time, method of attack, target, attacked country, etc., of each case, which matches the needs of this study.

In order to transform the data into a terrorist organization indexing approach suitable for this problem, this study follows such steps for data collection: (1) Excluding incomplete data due to loss of START files in 1993. (2) Excluding cases marked as "Unknown" in the "gname" column. (3) Excluding terrorist organizations with no more than one attack, cause these groups' attack tendency cannot be calculated. Since most terrorist organizations do not last long and often fall within a short period, it is challenging to obtain panel data on a year-by-year basis. Therefore, in order to ensure the completeness of the data, this article finally obtains a total of 1825 terrorist organizations' cross-sectional data spanning half a century ($N = 1{,}825$).

4.2. Dependent Variables

According to the conceptual explanatory model in **Figure 3**, the concept of the dependent variable is "Terrorist organization tends explosive attack." For a given terrorist organization, this study

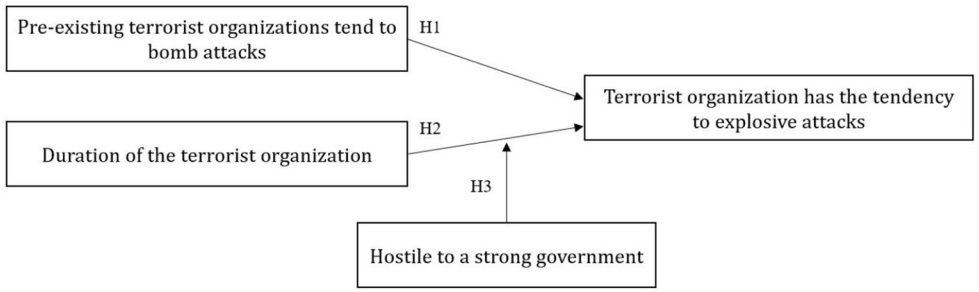


FIGURE 3 | A hypothetical model of the terrorist organizations to conduct explosive attacks.

measures it using a 0-1 binary variable. For attacks launched by a specific terrorist organization, if explosive attacks are the most frequent, more than other types in GTD, then the dependent variable is marked with "1," and if explosive attacks are not the most, then marked with "0." It is worth noting that if an organization has the same total counts of two attack types, then this study assumes that the organization tends toward the first occurred type.

4.3. Independent Variables

"Pre-existing terrorist organizations tend to explosive attacks" is the independent variable for H1. If a specific terrorist organization operates in the same country where the later organization specified in the dependent variable is primarily active, and before the latter's first activity, it has already been carrying out terrorist attacks, this specific organization is considered to be a "pre-existing" group. It is worth noting that there is usually more than one pre-existing terrorist organization for most organizations considered in the dependent variable. Here, the "pre-existing terrorist organization" is subject to temporal and geographical constraints to ensure logical integrity and constraining chronological relations to prevent the endogenous problems of reverse causation. For each certain terrorist organization mentioned in the dependent variable, once the collection of pre-existing groups has been identified, the tendency to explosive attack can be calculated for each pre-existing organization based on the principle of "whether the explosive attack is the most numerous among the eight types of terrorist attack." Finally, if the proportion of pre-existing terrorist organizations with a tendency to explosive exceeds 50%, it is considered that the value of this independent variable is "1," otherwise, it is "0." It is important to note that if a terrorist organization appears for the first time in a specific country, there is no pre-existing group for it, which means the independent variable is set to "0," and there is no object to imitate.

The concept "Duration of the terrorist organization" is firstly calculated as a continuous value accurate to year-level, with the results for a specific terrorist organization being the difference between the "iyear" value of the first attack and the last attack. Namely, the margin between the years. Secondly, considering that other explanatory variables are categorical variables and that scholars such as Yang and Zhou (2005) treat the age of firms in segments when applying institutional theory to the study of organizational behavior, this study coded the terrorist organization duration categorization as follows: "1" for terrorist organizations whose duration year margin is 0 in the first step, which means these groups are destroyed in a short period of time; "2" for organizations of one year's duration; the code is "3" for a duration of two years; "4" for three to five years; and "5" for more than six years. Ultimately, long-standing and notorious organizations such as the Taliban and Al-Qaida are in the category "5."

4.4. Moderating Variable

The concept "Hostile to a strong government" is the moderating variable for H3. In order to ensure the reasonableness of the measure, this study first uses the "A-Government Stability" s from the International Country Risk Guide (ICRG) (Howell, 2011; PRS.Group, 2021) to measure the strength of governments around the world. The ICRG evaluates each country's annual "A-Government Stability" rating based on three indicators: government unity, legislative strength, and popular support. The highest score for each indicator is 4, with a higher score indicating a stronger government. The average government stability for all countries since 1984 is 7.57, using this s as a boundary to classify high and low groups, a total of 67 countries are relatively stronger, including China (8.83), Canada (8.05), Finland (8.05), and the United States (8.54). Secondly, since the records of GTD started in 1970 and ICRG in 1984, the ICRG lacks early records from regions such as the former Soviet Union and parts of Africa. In order to avoid large deviations from the facts, this study relaxes the precision of the judgment of "whether there is a strong government" to the "region" level in GTD. Ultimately, "East Asia," "Western Europe," "North America," and "Australia and Oceania" are considered regions with relatively strong governments. For a given terrorist organization, the value of this dependent variable is "1," if its primary activity area is one of the above four. Further, the "Central America and the Caribbean," "South America," "South-East Asia," "South Asia," "Central Asia," Eastern Europe," "The Middle East and North Africa," "Sub-Saharan Africa" are considered to be regions with relatively weak governments. If a terrorist organization mainly attack countries in these areas, then the independent variable is "0." The countries and regions in which terrorist organizations

TABLE 2 | Variables identification and definition.

Variable	Meaning	Variable ID	Variable format
Dependent	Terrorist organization has the tendency to explosive attack	TENDENCY	Binary
Independent	Pre-existing terrorist organizations tend to explosive attacks	EX_TEND	Binary
	Duration of the terrorist organization	AGE	1-5 ordered categorical
Moderation	Hostile to a strong government	ANTI	Binary
	Whether the terrorist organization has a background of transnational attacks	TRANS	Binary
	Success rate of explosive attacks of the terrorist organization	SUCCESS	Continuous
Controls	Success rate of explosive attacks by pre-existing terrorist organizations	EX_ SUCCESS	Continuous
	whether a terrorist organization cooperates with an organization which has explosive tendency	COOP	Binary
	Whether terrorist organizations operate mainly in relatively high-risk areas	R_AREA	Binary
	The number of attacks by terrorist organizations	FREQ	1-5 ordered categorical

TABLE 3 | Descriptive statistics and multi-collinearity analysis of variables.

Variable	Min	Max	Mean	Std.	VIF	1	2	3	4	5	6	7	8	9	10
TENDENCY	0	1	0.45	0.498	\	1.000									
EX_TEND	0	1	0.38	0.486	2.154	0.163**	1.000								
ANTI	0	1	0.29	0.454	1.582	0.105**	0.247**	1.000							
AGE	1	5	3.025	1.687	1.471	−0.016	-0.087**	−0.101**	1.000						
TRANS	0	1	0.28	0.449	1.337	−0.009	-0.059*	−0.046*	0.452**	1.000					
SUCCESS	0	1	0.367	0.355	1.082	0.807**	0.174**	0.072**	−0.040	−0.023	1.000				
EX_SUCCESS	0	1	0.341	0.193	2.254	0.180**	0.774**	0.229**	−0.106**	−0.129**	0.215**	1.000			
COOP	0	1	0.07	0.255	1.122	0.067**	0.053*	−0.133**	0.086**	0.000	0.073**	0.083**	1.000		
R_AREA	0	1	0.418	0.493	1.568	0.055*	−0.047*	−0.541**	0.093**	0.005	0.100**	0.087**	0.202**	1.000	
FREQ	1	5	1.399	0.712	1.456	0.096**	−0.035	−0.091**	0.516**	0.363**	0.069**	−0.095**	0.240**	0.087**	1.000

*N = 1,825; *p < 0.05; **p < 0.01.*

are mainly active are the plurals of the two corresponding records corresponding in the GTD.

4.5. Control Variables

In addition to the above variables, since there are few empirical studies on the behavior of terrorist organizations, this study proposes the following six control variables concerning the control of organizational size and structure by Yang and Zhou (2005): (a) "Whether the terrorist organization has a background of transnational attacks," if a terrorist organization has carried out attacks in multiple countries and regions according to GTD records, then the code is 1, and vice versa is 0. (b) "Success rate of explosive attacks of the terrorist organization." (c) "Success rate of explosive attacks by pre-existing terrorist organizations," which is calculated as the proportion of terrorist attacks that are considered "successful" by GTD. Both the control variables (b) and (c) take into account that a higher success rate may impact the tendency to explosive attacks. (d) In order to prevent the effects of cooperation on organizational similarity in the normative isomorphism perspective, "whether a terrorist organization cooperates with an organization which has explosive tendency" is selected as the fourth control variable. If the particular terrorist organization is present in one or more of the attacks recorded by the GTD together with other explosive-prone organizations, the code is 1, and 0 otherwise. (e) Taking into account the impact of warfare on the propensity to bomb, for example, through the relative availability of bomb-making materials, it is crucial to take into account "Whether terrorist organizations operate mainly in relatively high-risk areas." If a terrorist organization is mainly active in the Middle East and North Africa, Southeast Asia, South Asia, and Central Asia, the code is 1, and the opposite is 0. (f) Similar to the transnational context, in order to further control the size of the organization, this study controls "The number of attacks by terrorist organizations" and codes the number of terrorist attacks from 0–10, 11–100, 101–500, 501–1000 and above 1001 to a scale of 1–5.

A brief identification and explanation of all the above variables in this study are shown in **Table 2**.

5. RESULTS

5.1. Descriptive Statistics and Multi-Collinearity Analysis

This study uses the logistic regression method to analyze 1,825 cross-sectional data from the GTD. **Table 3** shows the results of descriptive statistics and multi-collinearity analysis. As the variables are mainly categorical variables, Spearman's correlation test was used. From the table: (a) The data for the remaining variables are well distributed, except for the COOP with a mean of 0.07, which is heavily skewed to the left. (b) EX_TEND was significantly correlated with TENDENCY, with

a correlation coefficient of 0.163 ($p < 0.01$), ANTI is also significantly correlated with TENDENCY, with a coefficient of 0.105 ($p < 0.01$), H1 and H2 are initially confirmed. (c) AGE was negatively correlated with TENDENCY, but the correlation coefficient −0.016 was not significant ($p > 0.05$), the H3 needs further examination. (d) The variance inflation factors (VIF) of the main variables are between 1.082 and 2.254, smaller than the criterion for multi-collinearity discrimination (<5). This indicates that the problem of multi-collinearity is not serious, but in order to ensure the experimental rigor, the correlation coefficients greater than 0.7 are excluded from the regression analysis. This means SUCCESS and EX_SUCCESS are excluded from the regression analysis.

5.2. Logistic Regression Analysis Method for Cross-Sectional Data

Logistic regression analysis is applicable to problem scenarios where the dependent variable is a binary variable, and does not emphasize whether the variables are normally distributed, thus it is adopted for hypothesis testing in this article. The logistic regression method is as shown in Equation (1):

$$Logistic(p) = ln\frac{p}{1-p} = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + ... + \beta_n x_n + \varepsilon \quad (1)$$

where $p = p_{(y=1)}$ represents the probability that the dependent variable y is equal to 1, which means the probability that a terrorist organization has a tendency to exposion attack. $\frac{p}{1-p}$ is the odds of experiencing an event (odds). $\beta_{i(i=0,1,2...n)}$ is the regression coefficient of the variable, β_0 is the constant, ε is the random error. $x_{i(i=0,1,2.....n)}$ are other variables, and n is the number of variables. The logistic model uses the maximum likelihood method for parameter estimation.

5.3. Results of Logistic Regression Analysis

This article is divided into five models for logistic regression analysis. Model 0 is the base model with only four control variables added: TRANS, COOP, R_AREA. FREQ, as a comparative baseline for subsequent models. Models 1-2, respectively, add EX_TEND and AGE as independent variables to test H1-H2. Model 3 adds a moderating effect, which means the product term of ANTI and AGE. Model 4 is a full-variable model used to reflect whether the results are robust or not tentatively.

In Model 1 of **Table 4**, the EX_TEND coefficient of 0.690 is significantly positive ($p < 0.001$), indicating that the H1 Confirmation that the "tendency of pre-existing terrorist organizations to explosive attacks" does have a positive effect on the tendency of later ones. From Equation (1), the primary effect size of H1 is $Exp(B\_1) = e(0.690) = 1.994$, which means if the tendency to the explosive attack of a pre-existing terrorist organization changes from 0 to 1 (the independent variable increases by 1), and the odds of the later terrorist organizations to form explosive tendency are 1.994 times greater. The above analysis shows that the mimetic isomorphism effect based on institutional theory significantly impacts the formation of terrorist group explosive tendencies. In model 2, the coefficient of AGE is -0.093 ($p < 0.01$), which means H2 is confirmed and "Duration of the terrorist organization" does diminish its tendency to explosive attacks. The size of this negative effect is $Exp(B\_3) = 0.912$, which indicates that once the duration of a terrorist organization increases by one level, the probability of forming explosive tendency is only 91.2%, which is about 10% lower than the original probability. These two hypotheses were confirmed in the separate models and in the full-variable model 4, where the coefficients are significant, and the sign directions do not change, which to some extent indicates the robustness of the results. The regression result of the moderating effect of ANTI∗AGE in H3 is shown in models 3 and 4, which reveals the coefficients of interaction are both respectively positive: 0.155 ($p < 0.05$) and 0.137 ($p < 0.05$). This result confirms H3 and shows that the ANTI as a moderating variable significantly reduces the negative effect of terrorist organization duration on the formation of explosive tendency.

5.4. Robustness Test

In order to ensure the reliability of the above results, this study chose another measure of the dependent variable to test the robustness of the model. In section 3, the concept of "whether a terrorist organization has the tendency to explosive attack" as the dependent variable is measured based on "whether the number of bombing/explosive is the most among the eight methods." In this section, the measure is changed to "whether the number of bombing attacks exceeds 50% of the total number" during the robustness test, which makes the measure stricter, while the dependent variable remains a binary variable. Robustness tests were conducted by replacing variables of the same nature: the models R0-R4 are based on the original logistic regression model, with the dependent variable is replaced by the new measure. The Robustness test results are shown in **Table 5**. The three confirmed hypotheses also hold in the robustness test. The EX_TEND coefficient is 0.816 (p <0.001), and the effect size is $Exp(B\_1) = 2.262$. The AGE coefficient is −0.164 (p <0.001), negative effect $Exp(B\_3)$=0.849. The coefficients of the two main effects remain significant and increase in size, further illustrating the reliability of the hypothesis. The moderating effect is also confirmed, with an intersection coefficient of 0.175 ($p < 0.01$) for model R3 in **Table 5**. The above findings are all valid for the full variables model R4. The above analysis shows that the model passes the robustness test, and the results are reliable.

This study further graphically analyzes the moderating effects of model 3 in **Table 4** and model R3 in **Table 5** to understand better the role of coercive and mimetic isomorphisms in forming terrorist organizations' explosive tendencies. The horizontal axis of the figure shows the high and low groups of the duration "AGE," using the mean plus or minus one standard deviation as the high-low grouping boundary, with the vertical axis being the probability that a terrorist organization tends to explosive attacks. As shown in **Figure 4A**, where the dependent variable is "whether terrorist organizations use explosive attacks the most of the eight methods," the dashed regulatory effect group was clearly above the Solid line unmodulated effects group. This phenomenon suggests that terrorist organizations operating in areas with a stable government are more prone to explosive attacks than

TABLE 4 | Results of logistic regression analysis.

Variable		Model 0	Model 1	Model 2	Model 3	Model 4
Controls	TRANS	−0.240*	−0.204^{+}	−0.135	−0.122	−0.108
		(0.116)	(0.118)	(0.123)	(0.125)	(0.126)
	COOP	0.252	0.173	0.249	0.275	0.209
		(0.196)	(0.199)	(0.197)	(0.198)	(0.201)
	R_AREA	0.163^{+}	0.209*	0.184^{+}	0.652***	0.599***
		(0.098)	(0.100)	(0.099)	(0.121)	(0.122)
	FREQ	0.322***	0.335***	0.403***	0.437***	0.431***
		(0.076)	(0.078)	(0.083)	(0.084)	(0.085)
Independent	EX_TEND		0.690***			0.523***
			(0.099)			(0.103)
	AGE			-0.093**	−0.136***	−0.121**
				(0.034)	(0.040)	(0.040)
	ANTI				0.468*	0.353
					(0.219)	(0.222)
Interaction	AGE * ANTI				0.155*	0.137*
					(0.063)	(0.063)
Intercept	Constant	−0.676***	−0.987***	−0.548***	−0.933***	−1.103***
		(0.113)	(0.124)	(0.123)	(0.156)	(0.161)
N		1,825	1,825	1,825	1,825	1,825

$^{+}p < 0.1$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Standard errors of the coefficient estimates are in parentheses.

TABLE 5 | Robustness test results.

Variable		Model R0	Model R1	Model R2	Model R3	Model R4
Controls	TRANS	−0.271*	−0.231^{+}	−0.084	−0.072	−0.050
		(0.122)	(0.125)	(0.130)	(0.133)	(0.134)
	COOP	0.402*	0.311	0.399*	0.436*	0.360^{+}
		(0.197)	(0.201)	(0.198)	(0.201)	(0.203)
	R_AREA	0.033	0.086	0.069	0.611***	0.543***
		(0.102)	(0.105)	(0.103)	(0.131)	(0.133)
	FREQ	0.021	0.027	0.161^{+}	0.194*	0.181*
		(0.079)	(0.080)	(0.084)	(0.087)	(0.087)
Independent	EX_TEND		0.816***			0.634***
			(0.102)			(0.106)
	AGE			−0.164**	−0.221***	−0.203***
				(0.036)	(0.043)	(0.043)
	ANTI				0.512*	0.373
					(0.224)	(0.229)
Interaction	AGE * ANTI				0.175**	0.152*
					(0.064)	(0.065)
Intercept	Constant	−0.647***	−1.017***	−0.421***	−0.846***	−1.050***
		(0.116)	(0.128)	(0.125)	(0.162)	(0.168)
N		1,825	1,825	1,825	1,825	1,825

$^{+}p < 0.1$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. Standard errors of the coefficient estimates are in parentheses.

those operating in areas with a weak government. At the same time, the probability of explosive tendency decreases significantly with increasing duration of terrorist organizations in the solid-line group without adjustment effect, which once again confirms the negative effect of terrorist organization duration on the tendency in H3. The negative effect of the duration is significantly mitigated in the dashed group corresponding to the moderating effect, and the slope is relatively flat. **Figure 4B** shows the moderating effect in the robustness analysis, and again, terrorist groups under the moderating effect are significantly more likely to prefer explosive attacks regardless of their duration. In summary, the four hypotheses, three main effects, and one moderating effect proposed in this article are all confirmed.

6. DISCUSSION

As the three hypotheses proposed in this study are validated, we will highlight how the analysis of explosive attack tendency isomorphism within institutional theory's perspective can

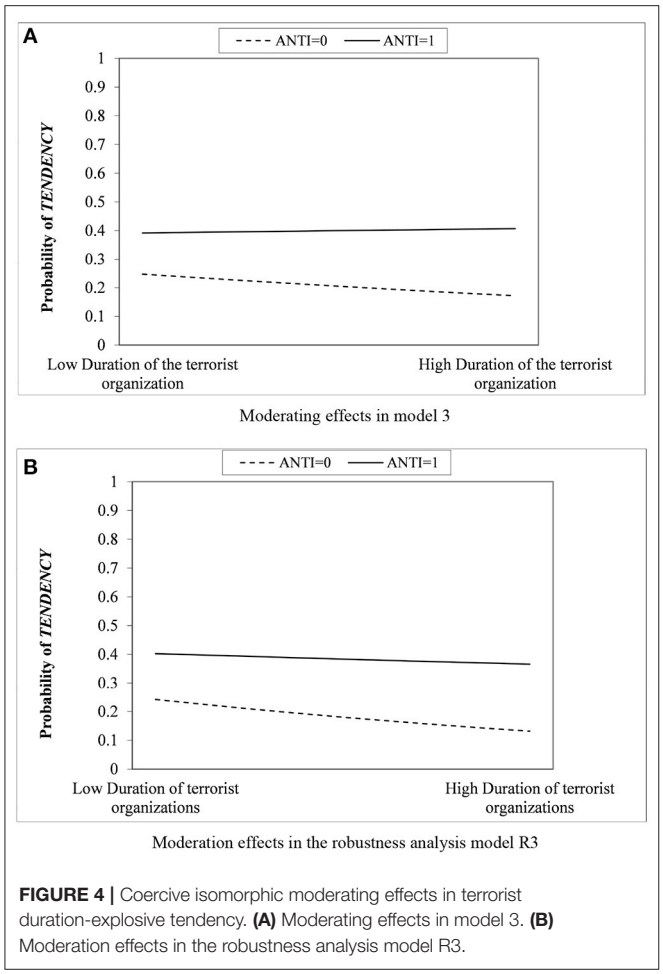


FIGURE 4 | Coercive isomorphic moderating effects in terrorist duration-explosive tendency. **(A)** Moderating effects in model 3. **(B)** Moderation effects in the robustness analysis model R3.

implicate CT practices. Meanwhile, we will also explore the limitations of the study.

The influence of pre-existing terrorist organizations on the explosive tendency of subsequent terrorist organizations operating primarily in the same countries is intense, and the mimetic isomorphic shows significant effects. It is crucial for states, security personnel and CT experts to interrupt this contagion-like process. The destruction of the learnable attack experience is one of the critical means. For example, when it is found that pirates want to learn from previous successful experience and continue operating in locations where there have been results, a successful rescue, to destroy the "this place is conducive to attack" experience, it can greatly ameliorate the security situation (Di Salvatore, 2018). This is helpful situational crime prevention (SCP) approach, which means adopting situational measures to reduce the chances of offending to prevent specific types of incidents (Clarke, 2013). The experiences formed from one successful attack consist of elements such as the target's vulnerability in this incident, the method of weapon usages, the results, etc. Strengthening protection for similar vulnerable targets, increasing the difficulty of acquiring similar weapons, and reducing the spread of fear may be effective ways to reduce learning among terrorist organizations.

Although the effect is not as strong as mimetic isomorphism, normative and coercive isomorphism also significantly impact the similarity of terrorist organizations. And these two isomorphic processes dialectically reveal the relationship between terrorist organizations and their institutional cages. The longer a terrorist organization survives, the more capable it becomes, and the richer its tactics and targets. If the country in which it operates is strong enough, then it may also suppress this trend. How to go beyond merely suppressing the diverse capabilities of terrorist organizations to further stop terrorist organizations and terrorism? The first answer is to address the root causes of terrorism. This is a long-term program that requires improvements in all aspects of politics, economics, conflict, etc., that we have mentioned. Without a turbulent institutional environment, the citizens will lose their reason to radicalize, potential supporters will abandon their commitment to terrorism, and terrorist groups' delusions of becoming more professional will only get more ridiculous. On the other hand, when the root causes are addressed, a formed terrorist organization may continue to operate until it is entirely physically eliminated (Crenshaw, 1981). At this point, it must be coupled with the short-term approaches discussed in the analysis of mimetic isomorphism, which is also highlighted by Bjørgo (2013): protecting the vulnerable targets, disrupting the planned attacks, mitigating tragic consequences, reducing feedback from attacks to terrorist organizations, etc.

Overall, while the trend of terrorist attacks is still severe, the number of global terrorist attacks has increased in the last decade. But with the involvement of studies in the field of terrorism and CT, this dismal situation may be reversed. It is also hoped that this article can provide some modest theoretical contributions to public security.

There are two main limitations of this article. First, it is challenging to obtain panel data containing a relatively large number of organizations. While GTD contains very detailed data on global terrorist attacks, unfortunately, many terrorist attacks are hard to know the terrorists or terrorist organizations that perpetrated them, which creates limitations. Second, we have not addressed the issue of transnational terrorist organizations sufficiently. As the three hypotheses concern, the current study focuses primarily on the institutional environment posed by a single country, while the more complex situations faced by transnational organizations we have not adequately considered. In future research, we will further apply institutional theory to study transnational terrorist organizations' behavioral patterns.

7. CONCLUSION

This article analyzes and empirically investigates the explosive tendency of terrorist organizations from three perspectives: coercive, normative, and mimetic isomorphism, based on institutional theory. The results indicate that (a) Terrorist organizations will learn from the experience of pre-existing terrorist organizations and that this imitative behavior will

contribute to the formation of explosive tendencies. (b) As the duration of a terrorist organization increases, its explosive tendency diminishes or disappears. This is due to the longer duration, which means the retention of strategic space for terrorist organizations, the weakness of governments, and increased bargaining power. At this point, multiple methods of a terrorist attack may be an option, and bombing is no longer the only choice. (c) Terrorist organizations often have little room for maneuver and little bargaining power when confronted with a strong government. This can lead to a preference for relatively more straightforward and more damaging explosive attacks when avenues such as hijacking and kidnapping are challenging to pursue. Thus, if terrorist groups operate primarily in strong government strongholds, their growth over time will not allow them to flourish. In the face of an intense government siege, explosive attacks are likely to remain at the of their propensity.

The above findings illustrate the applicability of the institutional theory in explaining the isomorphism of terrorist behavior, especially the convergence of attack methods. Moreover, they elucidate the role of coercive and normative isomorphic drivers in the isomorphism of terrorist behavior, which has received little attention in previous studies: unlike the isomorphic reasons why business organizations are subject to government regulation and industry norms, the claim of "legitimacy" of terrorist organizations is anti-government, the widespread use of bombings as a better bargaining tool for terrorist activities in order to survive in the general war on terror.

The study suggests that counter-terrorism approaches such as destroying the learnable experience of attacks, addressing the root causes of terrorism, and maintaining a strong government may be helpful in stopping increasing terrorist activities. These strategies imply popular support, unity, and coordination among all counter-terrorism departments, which firstly curbs the activities of all terrorist organizations and blocks the communication between them. Finally, with a strong government suppression, the existence of terrorist organizations will be relatively shorter, which will also make their strategic space narrow and their ability to do evil diminished. In addition, this research speculates that end-of-the-road terrorist organizations may be more tend to explosive attacks, and future research will attempt to examine the issue of terrorist attack prediction in conjunction with this analysis.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found at: Global Terrorism Dtabase, https://www.start.umd.edu/gtd/.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

FUNDING

This work was supported by the National Key Research and Development Program of China (Award numbers: 2018YFC0807500) and National Natural Science Foundation of China (Award numbers: 71974067 and 71821001).

REFERENCES

Ajide, K. B., Adenuga, J. I., and Raheem, I. D. (2020). Natural resource rents, political regimes and terrorism in Africa. *Int. Econ.* 162, 50–66. doi: 10.1016/j.inteco.2020.04.003

Ajide, K. B., and Alimi, O. Y. (2021). Income inequality, human capital and terrorism in Africa: Beyond exploratory analytics. *Int. Econ.* 165:218–240. doi: 10.1016/j.inteco.2021.01.003

Baek, I., and Bouzinov, M. (2021). Does democratic progress deter terrorist incidents? *Eur. J. Polit. Econ.* 66:101951. doi: 10.1016/j.ejpoleco.2020.101951

Bagchi, A., and Paul, J. A. (2018). Youth unemployment and terrorism in the MENAP (middle east, north Africa, Afghanistan, and Pakistan) region. *Socio Econ. Plann. Sci.* 64:9–20. doi: 10.1016/j.seps.2017.12.003

Bjørgo, T. (2013). *Strategies for Preventing Terrorism*. (New York, NY: Palgrave Macmillan).

Braithwaite, A., and Johnson, S. D. (2012). Space-time modeling of insurgency and counterinsurgency in Iraq. *J. Quant. Criminol.* 28, 31–48. doi: 10.1007/s10940-011-9152-8

Brouthers, L. E., O'Donnell, E., and Hadjimarcou, J. (2005). Generic product strategies for emerging market exports into triad nation markets: a mimetic isomorphism approach. *J. Manag. Stud.* 42, 225–245. doi: 10.1111/j.1467-6486.2005.00495.x

Bruce, S. (2009). *How Smart Are Islamic Terrorists? - Schneier on Security*. Available online at: https://www.schneier.com/blog/archives/2009/11/how_smart_are_i.html (accessed December 2021).

Burruss, G. W., and Giblin, M. J. (2014). Modeling isomorphism on policing innovation: the role of institutional pressures in adopting community-oriented policing. *Crime Delinquency* 60, 331–355. doi: 10.1177/0011128709340225

Byman, D. (2020). Understanding, and misunderstanding, state sponsorship of terrorism. *Stud. Conflict Terrorism* doi: 10.1080/1057610X.2020.1738682. [Epub ahead of print].

Carter, J. G. (2016). Institutional pressures and isomorphism: the impact on intelligence-led policing adoption. *Police Quart.* 19, 435–460. doi: 10.1177/1098611116639536

Cirjak Antonia (2020). *10 Largest Mass Suicides in History - Worldatlas*. Available online at: https://www.worldatlas.com/articles/10-largest-mass-suicides-in-history.html (accessed December 2021).

Clarke, R. V. (2013). "Situational crime prevention," in *Environmental Criminology and Crime Analysis* (Devon, AL: Willan), 200–216.

Clarke, R. V. G., and Newman, G. R. (2006). *Outsmarting the Terrorists*. Westport, CT: Greenwood Publishing Group.

Crenshaw, M. (1981). The causes of terrorism. *Comparat. Polit.* 13, 379–399. doi: 10.2307/421717

Davis, P. S., Desai, A. B., and Francis, J. D. (2000). Mode of international entry: an isomorphism perspective. *J. Int. Bus. Stud.* 31, 239–258. doi: 10.1057/PALGRAVE.JIBS.8490904

Deligonul, S., Elg, U., Cavusgil, E., and Ghauri, P. N. (2013). Developing strategic supplier networks: an institutional perspective. *J. Bus. Res.* 66, 506–515. doi: 10.1016/j.jbusres.2011.12.003

Di Salvatore, J. (2018). Does criminal violence spread? Contagion and counter-contagion mechanisms of piracy. *Polit. Geography* 66, 14–33. doi: 10.1016/j.polgeo.2018.07.004

Dimaggio, P. (1988). "Interest and agency in institutional theory," in *Research on Institutional Patterns: Environment and Culture* (Cambridge: Ballinger Publishing Co).

DiMaggio, P. J., and Powell, W. W. (1983). The iron cage revisited: institutional isomorphism and collective rationality in organizational fields. *Am. Sociol. Rev.* 48, 147–160. doi: 10.2307/2095101

Dupont, B. (2015). Security networks and counter-terrorism: a reflection on the limits of adversarial isomorphism. in *Social Networks, Terrorism and Counter-Terrorism* (New York, NY: Routledge), 155–174.

Fu, P. P., Kennedy, J., Tata, J., Yukl, G., Bond, M. H., Peng, T.-K., et al. (2004). The impact of societal cultural values and individual social beliefs on the perceived effectiveness of managerial influence strategies: a meso approach. *J. Int. Bus. Stud.* 35, 284–305. doi: 10.1057/palgrave.jibs.8400090

Ganor, B. (2008). Terrorist organization typologies and the probability of a boomerang effect. *Stud. Conflict Terrorism* 31, 269–283. doi: 10.1080/10576100801925208

Gao, Y. (2010). Mimetic isomorphism, market competition, perceived benefit and bribery of firms in transitional China. *Aust. J. Manag.* 35, 203–222. doi: 10.1177/0312896210370082

Gassebner, M., and Luechinger, S. (2011). Lock, stock, and barrel: a comprehensive assessment of the determinants of terror. *Publ. Choice* 149, 235–261. doi: 10.1007/s11127-011-9873-0

Giblin, M. J. (2006). Structural elaboration and institutional isomorphism: the case of crime analysis units. *Policing. Int. J. Police Strategies Manag.* 29, 643–664. doi: 10.1108/13639510610711583

Glebovskiy, A. (2019). Criminogenic isomorphism and groupthink in the business context. *Int. J. Org. Theory Behav.* 22, 22–42. doi: 10.1108/IJOTB-03-2018-0024

Guardian, M. (2001). *Scores Burnt, Shot in Angolan Bus Massacre - the Mail & Guardian*. Available online at: https://mg.co.za/article/2001-08-27-scores-burnt-shot-in-angolan-bus-massacre/ (accessed December 2021).

Helfstein, S. (2009). Governance of terror: new institutionalism and the evolution of terrorist organizations. *Publ. Admin. Rev.* 69, 727–739. doi: 10.1111/J.1540-6210.2009.02020.X

Hersberger-Langloh, S. E., Stühlinger, S., and Schnurbein, G. (2021). Institutional isomorphism and nonprofit managerialism: for better or worse? *Nonprofit Manag. Leadership* 31, 461–480. doi: 10.1002/nml.21441

Hitt, M. A. (2016). International strategy and institutional environments. *Cross Cult. Strategic Manag.* 23, 206–215. doi: 10.1108/CCSM-11-2015-0168

Howell, L. D. (2011). *International Country Risk Guide Methodology*. (East Syracuse, NY: PRS Group).

Hsu, H. Y., and Newman, G. R. (2016). "The situational approach to terrorism," in *The Handbook of the Criminology of Terrorism* (Hoboken, NJ: John Wiley & Sons, Inc.), 150–161.

Hu, X., Rodgers, K., and Lovrich, N. P. (2018). "We are more than crime fighters": social media images of police departments. *Police Quart.* 21, 544–572. doi: 10.1177/1098611118783991

Jongman, A. J. (2005). *Political Terrorism: A New Guide to Actors, Authors, Concepts, Data Bases, Theories, and Literature*. New York, NY: Routledge.

Kenney, M. (2009). *Organizational Learning and Islamic Militancy*. Washington, DC: National Institute of Justice, U.S. Department of Justice.

Kis-Katos, K., Liebert, H., and Schulze, G. G. (2011). On the origin of domestic and international terrorism. *Eur. J. Polit. Econ.* 27, S17–S36. doi: 10.1016/j.ejpoleco.2011.02.002

Krieger, T., and Meierrieks, D. (2019). Income inequality, redistribution and domestic terrorism. *World Develop.* 116, 125–136. doi: 10.1016/j.worlddev.2018.12.008

LaFree, G., and Dugan, L. (2007). Introducing the global terrorism database. *Terrorism Polit. Violence* 19, 181–204. doi: 10.1080/09546550701246817

Lanouar, C., and Shahzad, U. (2021). Terrorism and capital flows: the missed impact of terrorism in big cities. *Appl. Econ. Lett.* 28, 1626–1633. doi: 10.1080/13504851.2020.1861185

Marquis, C., Glynn, M. A., and Davis, G. F. (2007). Community isomorphism and corporate social action. *Acad. Manag. Rev.* 32, 925–945. doi: 10.5465/amr.2007.25275683

McCann, W. S., and Pimley, N. (2020). Mixed mandates: issues concerning organizational and statutory definitions of terrorism in the United States. *Terrorism Polit. Violence* 32, 807–830. doi: 10.1080/09546553.2017.1404457

Miles, J. A. (2012). *Management and Organization Theory: A Jossey-Bass Reader*, Vol. 9. San Francisco, CA: John Wiley & Sons.

Parker, T., and Sitter, N. (2016). The four horsemen of terrorism: it's not waves, it's strains. *Terrorism Polit. Violence* 28, 197–216. doi: 10.1080/09546553.2015.1112277

Phillips, B. J. (2014). Terrorist group cooperation and longevity. *Int. Stud. Quart.* 58, 336–347. doi: 10.1111/isqu.12073

PRS.Group (2021). *Prs Group, Inc. The International Country Risk Guide (Icrg)*. Available online at: https://www.prsgroup.com/explore-our-products/international-country-risk-guide/

Sanderson, T. M. (2004). Transnational terror and organized crime: blurring the lines. *SAIS Rev. Int. Affairs* 24, 49–61. doi: 10.1353/sais.2004.0020

Schumacher, M. J. and Schraeder, P. J. (2021). Does domestic political instability foster terrorism? Global evidence from the arab spring era (2011-14). *Stud. Conflict Terrorism* 44, 198–222. doi: 10.1080/1057610X.2018.1538124

Scott, W. R., and others (1995). *Institutions and Organizations*, Vol. 2. (Thousand Oaks, CA: Sage).

Shahzad, U., and Qin, F. (2019). New terrorism and capital flight: pre and post nine eleven analysis for Asia. *Ann. Econ. Finance* 20, 465–487. Retrieved from: http://aeconf.com/may2019.htm

Shahzad, U., Qin, F., and Farooq, U. (2019). Capital flight, terrorism and military expenditures: empirical evidence from sub-Sahara African and MENA region. *Glob. Loc. Econ. Rev.*, 23, 39–64. Retrieved from: http://www.gler.it/all_issues.htm

Shahzad, U., Sarwar, S., Farooq, M. U., and Qin, F. (2020). USAID, official development assistance and counter terrorism efforts: Pre and post 9/11 analysis for South Asia. *Socio Econ. Plan. Sci.* 69:100716. doi: 10.1016/j.seps.2019.06.001

Sly, L. and Ramadan, A. (2014). *Insurgents Seize Iraqi City of Mosul As Security Forces Flee - the Washington Post*. Retrieved from: https://www.washingtonpost.com/world/insurgents-seize-iraqi-city-of-mosul-as-troops-flee/2014/06/10/21061e87-8fcd-4ed3-bc94-0e309af0a674_story.html (accessed December 2021).

Soeters, J. L. (2008). "Afghanistan talks. experiential isomorphism in the military," in *Contributions to Conflict Management, Peace Economics and Development*, Vol. 7 (Bingley: Emerald (MCB UP)), 139–156.

START (2021). *National Consortium for the Study of Terrorism and Responses to Terrorism (Start). Global Terrorism Database (gtd)*. Available online at: https://start.umd.edu/gtd/ (accessed December 2021).

Terrorism-Research.com (2021). *Common Terrorist Incidents and Techniques*. Available online at: http://www.terrorism-research.com/incidents/ (accessed December 2021).

Ufere, N., Gaskin, J., Perelli, S., Somers, A., and Boland, R. (2020). Why is bribery pervasive among firms in sub-Saharan African countries? Multi-industry empirical evidence of organizational isomorphism. *J. Bus. Res.* 108, 92–104. doi: 10.1016/j.jbusres.2019.09.060

Venard, B. (2009). Organizational isomorphism and corruption: an empirical research in Russia. *J. Bus. Ethics* 89, 59–76. doi: 10.1007/s10551-008-9984-9

Warren, R. M. (2019). *Institutional Isomorphism and Human Trafficking Investigations* (Ph.D. Thesis), Walden University.

Yang, D., and Zhou, C. (2005). The motive force of enterprise's voluntariness to adopt the system of the standard environment manage-ment: a theoretic framework and a case study. *Manag. World* 1, 85–95. doi: 10.19744/j.cnki.11-1235/f.2005.02.010

Zach, F. J., Schnitzer, M., and Falk, M. (2021). Product diversification and isomorphism: the case of ski resorts and "me-too" innovation.

Ann. Tourism Res, 90, 103267. doi: 10.1016/j.annals.2021.103267

Zarakol, A. (2011). What makes terrorism modern? terrorism, legitimacy, and the international system. *Rev. Int. Stud.* 37, 2311–2336. doi: 10.1017/S0260210510001518

Zulfiqar, B., Fareed, Z., Shehzad, U., Shahzad, F., and Nabi, S. (2014). The impact of terrorism on FDI inflow in Pakistan. *Eur. J. Econ. Stud.* 10, 279–284. doi: 10.13187/es.2014.4.279

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Communication

REVIEW
published: 25 February 2022
doi: 10.3389/fcomm.2022.837386

Building Organizational Resilience Through Organizational Learning: A Systematic Review

Lise L. Evenseth[1], Maria Sydnes[1]* and Anne H. Gausdal[2]*

[1] Department of Technology and Safety, UiT the Arctic University of Norway, Tromsø, Norway, [2] Department of Leadership and Organisation, Kristiania University College, Oslo, Norway

OPEN ACCESS

Edited by:
Jarle Løwe Sørensen, University of South-Eastern Norway, Norway

Reviewed by:
Andreia de Bem Machado, Federal University of Santa Catarina, Brazil
Trygve Steiro, Norwegian University of Science and Technology, Norway

****Correspondence:***
Lise L. Evenseth
lise.l.evenseth@uit.no
Maria Sydnes
maria.sydnes@uit.no

Specialty section:
This article was submitted to Disaster Communications, a section of the journal Frontiers in Communication

Received: *16 December 2021*
Accepted: *31 January 2022*
Published: *25 February 2022*

Citation:
Evenseth LL, Sydnes M and Gausdal AH (2022) Building Organizational Resilience Through Organizational Learning: A Systematic Review. Front. Commun. 7:837386. doi: 10.3389/fcomm.2022.837386

With organizational environments becoming increasingly complex and volatile, the concept of "organizational resilience" has become the "new normal". Organizational resilience is a complex and multidimensional concept which builds on the myriad of capabilities that an organization develops during its lifecycle. As learning is an inherent and essential part of these developments, it has become a central theme in literature on organizational resilience. Although organizational resilience and organizational learning are inherently interrelated, little is known of the dynamics of effective learning that may enhance organizational resilience. This study explores how to achieve organizational learning that can serve to promote organizational resilience. Our aim is to contribute to a more comprehensive knowledge of the relation between organizational resilience and organizational learning. We present the results of a systematic literature review to assess how organizational learning may make organizations more resilient. As both organizational resilience and organizational learning are topics of practical importance, our study offers a specifically targeted investigation of this relation. We examine the relevant literature on organizational learning and resilience, identifying core themes and the connection between the two concepts. Further, we provide a detailed description of data collection and analysis. Data were analyzed thematically using the qualitative research software NVivo. Our review covered 41 empirical, 12 conceptual and 6 literature review articles, all indicating learning as mainly linked to adaptation capabilities. However, we find that learning is connected to all three stages of resilience that organizations need to develop resilience: anticipation, coping, and adaptation. Effective learning depends upon appropriate management of experiential learning, on a systemic approach to learning, on the organizational ability to unlearn, and on the existence of the context that facilitates organizational learning.

Keywords: organizational resilience, organizational learning, organizational unlearning, organizational capabilities, experiential learning, crisis management

INTRODUCTION

With organizational environments becoming more and more complex and volatile, the concept of "organizational resilience" (OR) has become increasingly significant for practice and research. OR is here understood as the organization's "ability to anticipate potential threats, to cope effectively with adverse events, and to adapt to changing conditions" (Duchek, 2020, p. 220). Thus, anticipation, coping, and adaptation represent three stages of OR. Further, the literature indicates that OR is an essential organizational meta-capability for the success of modern organizations (Parsons, 2010; Näswall et al., 2013; Britt et al., 2016; Suryaningtyas et al., 2019). OR has indeed become the "new normal" (Linnenluecke, 2017) regarding organizational survival as well as recovery and successful re-emergence after disruptions. Understanding OR is therefore more important than ever (Ruiz-Martin et al., 2018). However, OR is still an emerging field (Ma et al., 2018)—and a key question that remains unanswered is how to achieve it (Boin and Lodge, 2016; Chen R. et al., 2021).

Research is explicit on the complexity and multidimensional nature of OR: it is associated with an organization's capabilities to learn, adapt, and self-organize (Linnenluecke and Griffiths, 2010), where learning is an inherent and essential element (Boin and van Eeten, 2013). This links OR to learning processes (see, e.g., Lengnick-Hall et al., 2011; Rodríguez-Sánchez and Vera Perea, 2015), where learning has become a common theme in resilience literature. Khan et al. (2019, p. 18) argue, "[o]rganizational learning capability is positively related to building and sustaining organizational resilience capability." While OR is defined at the organizational level, the inherent learning is organizational learning (OL), understood as an "[ongoing] social process of individuals participating in situated practices that reproduce and expand organizational knowledge structures and link multiple levels of OL" (Popova-Nowak and Cseh, 2015, p. 318). Furthermore, research has noted the similarities between OR and OL (Sitkin, 1992; Linnenluecke and Griffiths, 2010), as both require routines, values, models, and capabilities essential for organizations facing uncertainty. OR has also been defined as an outcome of organizational learning (Sitkin, 1992; Sutcliffe and Vogus, 2003), suggesting that organizational learning capability may be enhanced by OR (Rodríguez-Sánchez et al., 2021). However, OR is also a process (Boin et al., 2010) that facilitates OL and feeds organizational self-development over time (Lombardi et al., 2021). This makes OL both an important precondition for OR which relies on past learning, and an outcome of it that fosters future learning (Vogus and Sutcliffe, 2007). OR and OL may therefore reinforce each other.

Although OR and OL are inherently interrelated, our understanding of the dynamics of effective learning is limited (Antonacopoulou and Sheaffer, 2014), and further study is needed of the relationship between organizational learning and resilience (Mousa et al., 2017, 2020; Rodríguez-Sánchez et al., 2021). Further research on learning connected to OR is needed to understand "the character of this learning and what specific resources give rise to it" (Vogus and Sutcliffe, 2007, p. 3421). Moreover, investigation is needed of what triggers learning and corresponding processes and exploring of the effective learning strategies that allow resilient organizations to avoid pathological learning cycles (Vogus and Sutcliffe, 2007). Our aim with this study is therefore to contribute to more comprehensive knowledge on the relationship between OR and OL and to further explore the relationship between them by asking the research question: *How to improve organizational learning to make organizations more resilient?*

THEORETICAL FRAMEWORK

OL assumes interaction of its multiple levels of analysis, including the individual, group, organizational, and inter-organizational levels (Lundberg, 1995; Örtenblad, 2004; Popova-Nowak and Cseh, 2015). Being a social process, OL is embedded in everyday organizational practice when individuals acquire, produce, reproduce, and expand organizational knowledge (Lave and Wenger, 1991; Gherardi et al., 1998; Gherardi and Nicolini, 2002; Gherardi, 2008; Chiva et al., 2014). This individual knowledge, either explicit or tacit (Cook and Yanow, 1993), must become part of organizational repository that includes tools, routines, social networks and transactive memory systems (Huber, 1991, p. 89–90; Walsh and Ungson, 1991; Argote and Ingram, 2000; Argote, 2011). OL directly affects organizations facing turbulence (Baker and Sinkula, 1999) and involves "the extraction of positive lessons from the negativity of life" (Giustiniano et al., 2018, p. 133) that are useful to the whole organization. OL will therefore directly affect how resilient organizational performance is (Giustiniano et al., 2018).

Learning is emergent in nature (Antonacopoulou and Sheaffer, 2014). As a continuous process, OL implies accomplishment of specific steps. However, what those steps are varies, though with certain overlaps, across the literature (see, e.g., Huber, 1991; Argyris and Schön, 1996; Crossan et al., 1999; Lawrence et al., 2005; Jones and Macpherson, 2006; Argote and Miron-Spektor, 2011; Argote et al., 2020). Further, OL may vary in complexity and outcomes. At the lower (single-loop) level, OL results in detection and correction of errors "without questioning or altering the underlying values of the system" (Argyris and Schön, 1978, p. 8). At the higher (double-loop) level of learning, "errors are corrected by changing the governing values and then the actions" (Argyris, 2002, p. 206). Triple-loop learning (deutero-learning) enables organizations to learn about their own learning processes (Argyris and Schön, 1978, 1996). OL may be exploratory—associated with "search, variation, risk taking, experimentation, play, flexibility, discovery and innovation" (March, 1991, p. 71), or exploitive—utilizing the "old certainties" (March, 1991, p. 71). The trade-off between the two is a key concern of studies of adaptive processes; organizations need to have an appropriate balance between these strategies (Levinthal and March, 1993) to maintain "ambidexterity" (Lavie et al., 2010). Importantly, OL is not necessarily always a conscious or intentional effort, neither does it imply behavioral change (Hernes and Irgens, 2013) or always increase the learner's effectiveness (even potential effectiveness); finally, it does not

always lead to true knowledge, as organizations "can incorrectly learn, and they can correctly learn that which is incorrect" (Huber, 1991, p. 89).

Organizations struggle to implement OL (Lipshitz et al., 2002; Reich, 2007; Garvin et al., 2008; Taylor et al., 2010; Antonacopoulou and Sheaffer, 2014) due to a wide range of barriers (see, e.g., Schilling and Kluge, 2009). Productive OL is complex and relies on the interaction of various facets—cultural, psychological, policy, and contextual (Lipshitz et al., 2002; see also Garvin, 1993). These interactions may produce differing configurations and will vary across organizations. Experience has a special role as a key prerequisite for OL, but experience is extremely diverse in nature (Argote and Todorova, 2007; Argote, 2011; Argote and Miron-Spektor, 2011) and its relevance is only partial (Weick and Sutcliffe, 2015). In order for experience to be a "good teacher" (March, 2010) organizations must understand its nature and how different types of experience interplay (Argote and Miron-Spektor, 2011). The relationship between the experience and learning processes and outcomes is moderated by context (Argote, 2011, p. 441). Effective OL relies on a suitable context (Antonacopoulou and Chiva, 2007, p. 289) that can be complex and multidimensional (Argote and Miron-Spektor, 2011): *inter alia,* external organizational environments, organizational culture, strategy and structure, power relationship within the organization and inter-organizational processes and interactions. The contextual components through which learning occurs are active, whereas others that shape the active context are latent (see Argote and Miron-Spektor, 2011 for details).

Thus, OR is founded on learning processes (assessment, sense making, distilling lessons learned and integration of new understandings into existing practice) that are embedded in organizational routines (Powley and Cameron, 2020) that penetrate all stages of OR (Duchek, 2020). Achieving OR requires commitment and studying this commitment implies an enquiry into organizational learning, knowledge, and capability development (Weick and Sutcliffe, 2015, p. 108). Research has noted that different types of resilience associate with different learning strategies: adaptive resilience has been associated with single-loop learning (Lombardi et al., 2021, p. 2). In contrast, reactive resilience refers to the ability to view disruptions as sources of learning and growth at various organizational levels, where organizations must adopt new practices based on their experience, resulting in a double-loop learning. Resilience also entails a process of deutero-learning or "learning to learn" (Andersen, 2016), thus requiring a completely new experimentation approach. OR is enhanced when organizations build routines that can facilitate OL. The major challenge for an organization that aims at enabling resilience is to establish the right learning routines (see, e.g., Kayes, 2015): that is to say, those that achieve effective/productive OL.

METHODS

A systematic literature review (SLR) was chosen since it facilitates gathering of a wide range of relevant sources (Crossan and Apaydin, 2010) and ensures clarity of inclusion and exclusion criteria (Mackay and Zundel, 2017)—important when, as with OR, intellectual coherence or a standard theoretical framework is lacking (Liñán and Fayolle, 2015). Our review was outcomes-oriented, aiming to identify "central issues" (Cooper, 1988, p. 109); relevant literature was retrieved through an exhaustive review with selective citation, to consider all relevant publications for the research question. SLR involves two stages: a sampling and an analytical stage (**Figure 1**).

Conducting the Review

The Sampling Stage

Our initial search criteria were broad to include as many relevant results as possible. To obtain an overview of the available literature, the following databases were used: Science Direct, Web of Knowledge (Search in the core collection) and Google Scholar (for the latest publications and gray literature).[1] As Google Scholar is a compilation of records from other databases (Kugley et al., 2017) several articles had already been identified by Science Direct and Web of knowledge. All databases are frequently used by researchers of various disciplines (Xiao and Watson, 2019). The literature search was performed by the first author, in the period March–May 2021, covering publications between 1900 and 2021. A diary was made to keep record of the results, with search dates, search strings and results.

Search strings were developed by applying the keywords "organizational resilience" and "organizational learning". In Web of Knowledge, the Boolean operator (AND) was applied together with truncation symbol of the asterisk to include all forms of the words [TS = (resilien* AND organi* AND learning)]. The same keywords were applied in Science Direct; as both UK and US spelling variants are supported, there was no need for truncation symbol. Google Scholar offers limited search terms options, and the selection is not as transparent as Web of Knowledge and Science Direct. However, we performed a search in Google Scholar to broaden the number of publications and ensure the latest articles from all fields and disciplines. Only the three first pages were included. The initial search performed by the first author yielded 2,985 articles. Next, the same author went through the abstracts and keywords. In cases where abstracts were not sufficiently informative, the article was read through quickly. Duplicates were removed, which reduced the number of articles from 170 to 165.

The following criteria were used in the screening process resulting in 2,985 publications:

Inclusion Criteria

1. Empirical, conceptual, and theoretically oriented publications about organizational learning within organizational resilience
2. Publications written in English

[1] "Grey literature stands for manifold document types produced on all levels of government, academics, business and industry in print and electronic formats that are protected by intellectual property rights, of sufficient quality to be collected and preserved by library holdings or institutional repositories, but not controlled by commercial publishers, i.e., where publishing is not the primary activity of the producing body" (Schöpfel, 2010).

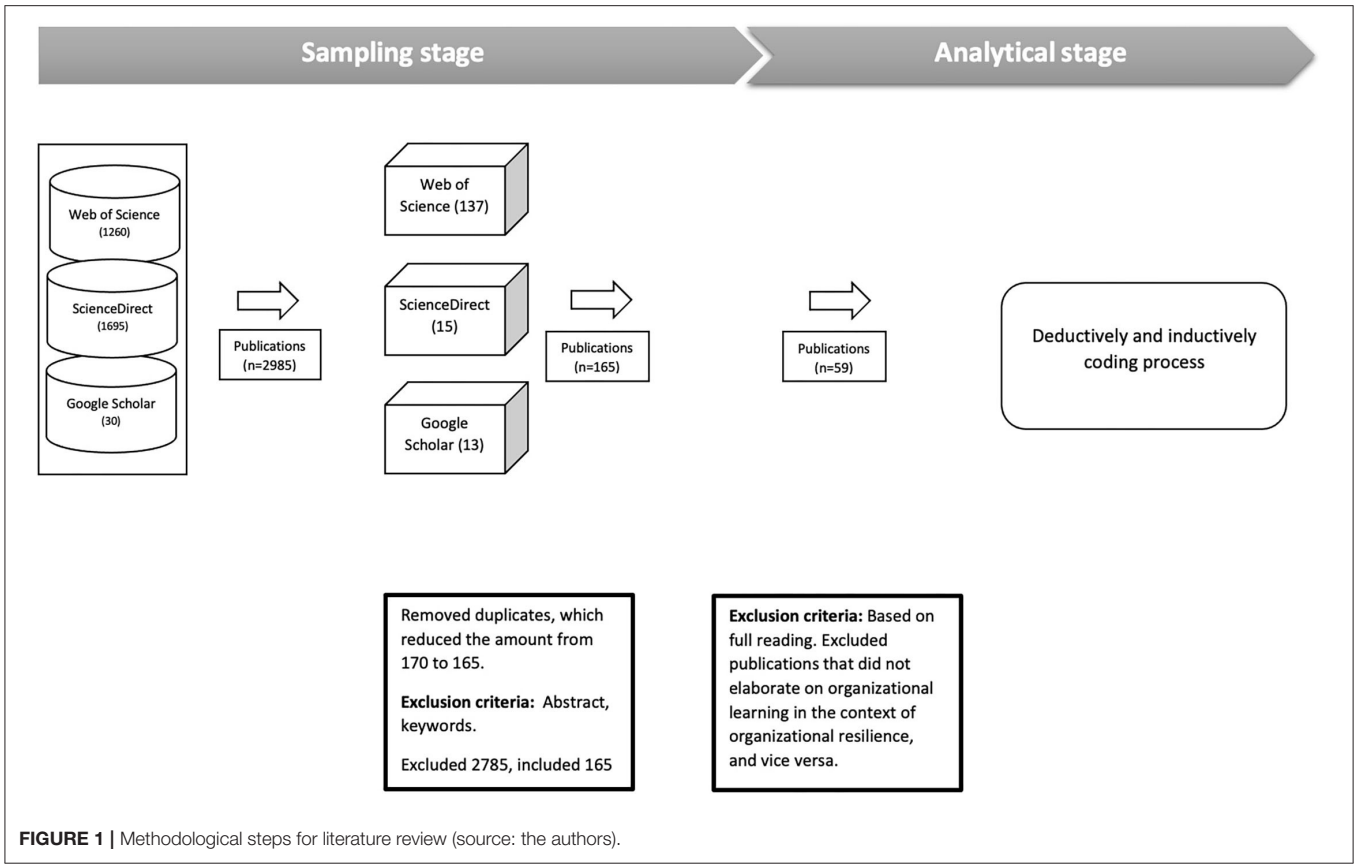


FIGURE 1 | Methodological steps for literature review (source: the authors).

3. Article type (applied only in Science Direct): Review articles, research articles, book chapters, conference abstracts and data articles
4. Subject areas (only in Science Direct): Social sciences, environmental science, business, management and accounting, engineering

Exclusion Criteria

1. Non-academic journals
2. Publications not issued in English or Norwegian
3. Article type (only in Science Direct): encyclopedias, book reviews, case reports, conference info, correspondence, discussions, editorials, errata; examinations, mini-reviews, news, practice guidelines, short communications, software publications, other
4. Subject areas (only in Science Direct): medicine and dentistry, psychology, agricultural and biological sciences, computer science, energy, neuro-science

Analytical Stage

The articles were randomly distributed to the three authors for a full reading, so that each article could be sorted as follows: (1) How organizational learning contributes to organizational resilience; (2) How OR contributes to organizational learning; (3) Uncertain. Articles placed in the latter category were discussed and given an additional full reading by the first author before a decision on category placement, or exclusion was made. As a result of this analytical screening process, 59 articles were included in the final review. After the phases of thematic analysis (Braun and Clarke, 2006) the articles were coded in NVivo 20 (Release 1.5). A deductive coding scheme was developed, based partly on Boyatzis (1998) approach. Theory on organizational learning informed the following deductive coding categories: experience; practices; strategies; effective learning; mechanisms; knowledge; processes and context. The Duchek (2020) conceptualization of resilience informed the codes: anticipation; coping; adaptation. The coding process started deductively; we inductively created additional codes underway. The first round of coding was performed by the first author and then presented to the co-authors. The second round of coding was performed by the first and second authors, and themes were created when we found "something important in relation to the overall research question" (Braun and Clarke, 2006, p. 83). Data were aggregated into clustered codes (Miles and Huberman, 1994). A memo of the coding process was kept in NVivo. Analysis of our findings is presented below.

LITERATURE REVIEW

The literature on organizational resilience has expanded massively in recent years, developing from being highly conceptual to containing increasingly more empirical contributions. Our 59-article review is presented in **Table 1**:

TABLE 1 | Overview of articles and stage of organizational resilience for their organizational learning focus (Source: the authors).

References	Type	Method*	Context**	Journal	OR stage
Adini et al. (2017)	LR	Systematic Literature Review and Modified Delphi	*Safety*	*Technological Forecasting and Social Change*	No
Al-Atwi et al. (2021)	E	Quantitative	Wide range of industries (Middle East)	*International Business Review*	Coping Adaptation
Anderson et al. (2020)	C	*	*Healthcare*	*Applied Ergonomics*	Anticipation Adaptation
Annarelli et al. (2020)	E	Quantitative Case study	Large service company (Europe)	*Sustainability*	Adaptation
Azadegan et al. (2019)	E	Quantitative	Manufacturing (Sweden; Switzerland; Germany)	*International Journal of Production Economics*	No
Battisti et al. (2019)	E	Quantitative	SMEs (New Zealand)	*Journal of Business Research*	Adaptation
Bhaskara and Filimonau (2021)	E	Qualitative	Tourism enterprises (Bali)	*Journal of Hospitality and Tourism Management*	Coping Adaptation
Bragatto et al. (2021)	E	Quantitative	Seveso (high-risk) industries (Italy)	*Journal of Hospitality and Tourism Management*	No
Chand and Loosemore (2016)	E	Qualitative	Healthcare (Australia)	*Building Research and Information*	Adaptation
Chen K. D. et al. (2021)	E	Quantitative	Automotive supply networks	*Decision Sciences*	No
Crick and Bentley (2020)	E	Qualitative and Quantitative	Universities	*International Journal of Sustainable Engineering*	Adaptation
Dohaney et al. (2020)	E	Qualitative and Quantitative	Universities (New Zealand)	*International Journal of Disaster Risk Reduction*	No
Duchek et al. (2020)	C	*	**	*Business Research*	Anticipation Adaptation
Duchek (2020)	C	*	**	*Business Research*	Anticipation Coping Adaptation
Dutra et al. (2015)	E	Qualitative	Various organizations (Australia)	*Ocean and Coastal Management*	Adaptation
Ekstedt and Odegard (2015)	E	Qualitative	Healthcare (Sweden)	*Cognition Technology and Work*	No
Elliott and Macpherson (2010)	E	Qualitative	Local authorities (UK)	*Safety*	Coping Adaptation
Fannoun and Kerins (2019)	E	Qualitative	Software development (UK)	*Learning Organization*	No
Fasey et al. (2021)	E	Qualitative and Quantitative Delphi	Elite sport experts (UK, USA, Europe, Australasia)	*Psychology of Sport and Exercise*	Adaptation
Friday et al. (2021)	LR	Systematic review	Health care supply chains	*Journal of Humanitarian Logistics and Supply Chain Management*	Anticipation
Fridell et al. (2020)	LR	Scoping review	Healthcare	*International journal of health policy and management*	Adaptation
Gilson et al. (2020)	E	Qualitative	Healthcare (South Africa)	*Social Science and Medicine*	No
Gressgard and Hansen (2015)	E	Quantitative	Oil and gas (Norway)	*Reliability Engineering and System Safety*	No
Habiyaremye (2021)	E	Qualitative	SMEs (South Africa)	*Sustainability*	Adaptation
Hardy (2014)	C	Case study	Complex systems (USA)	*Annual Reliability and Maintainability Symposium.*	Anticipation Adaptation
Hecht et al. (2019)	E	Qualitative	Local food system (USA)	*Journal of the Academy of Nutrition and Dietetics*	Adaptation
Hegde et al. (2020a)	E	Qualitative	Healthcare (USA)	*Journal of Cognitive Engineering and Decision Making*	Anticipation
Hegde et al. (2020b)	E	Qualitative	Healthcare (USA)	*Applied Ergonomics*	Adaptation
Herbane (2019)	E	Quantitative	SMEs (UK)	*Entrepreneurship and Regional Development*	Adaptation
Hermelin et al. (2020)	E	Interactive research	Healthcare (Sweden)	*Cognition Technology and Work*	Anticipation Adaptation
Hillmann et al. (2018)	E	Qualitative (experimental character)	MBA students (Germany)	*Journal of Management Education*	Anticipation Coping
Hillmann and Guenther (2021)	LR	Systematic review	**	*International Journal of Management Reviews*	No

(Continued)

TABLE 1 | Continued

References	Type	Method*	Context**	Journal	OR stage
Johannesen et al. (2020)	E	Qualitative	Healthcare (Norway)	*Bmc Health Services Research*	No
Johnsen and Habrekke (2009)	E	Quantitative	Railways (UK)	In ESREL 2008 proceedings: *Safety, Reliability and Risk Analysis: Theory, Methods and Applications*	No
Johnsen and Stene (2014)	E	Qualitative and Quantitative	Aviation/space (USA)	In Steenbergen et al. (eds) *Safety, Reliability and Risk Analysis: Beyond the Horizon*	No
Khan et al. (2017)	E	Qualitative	Drinking water (Australia)	*Environmental Science-Water Research and Technology*	Adaptation
Klockner and Meredith (2020)	E	Quantitative	Road transport (Australia)	*Safety*	Adaptation
Manfield and Newey (2018)	C	*	Entrepreneurship	*International Journal of Entrepreneurial Behavior and Research*	Coping Adaptation
Martinelli et al. (2018)	E	Qualitative	SMEs (Italy)	*International Journal of Entrepreneurial Behavior and Research*	Adaptation
Morais-Storz and Nguyen (2017)	C	*	**	*Learning Organization*	Adaptation
Mousa et al. (2020)	E	Quantitative	Universities (Egypt)	*Journal of Workplace Learning*	No
Naimoli and Saxena (2018)	LR	Multiple purposive literature searches	Healthcare	*Health Policy and Planning*	Adaptation
Nicolletti et al. (2019)	E	Qualitative	Oil and gas (Brazil)	*Journal of Cleaner Production*	Adaptation
Nyman (2019)	E	Qualitative	Railway (Sweden)	*Risk Hazards and Crisis in Public Policy*	Adaptation
Orth and Schuldis (2021)	E	Quantitative	For-profit organizations (Germany; Austria)	*The Learning Organization*	Adaptation
Pal et al. (2014)	E	Qualitative and Quantitative	Textile SMEs (Sweden)	*International Journal of Production Economics*	Adaptation
Patriarca et al. (2018)	E	Quantitative	Healthcare (Central Europe)	*Safety and Health at Work*	Adaptation
Prasad et al. (2015)	C	*	Micro enterprises (The developing world)	*Disasters*	No
Provan et al. (2020)	C	*	Safety management	*Reliability Engineering and System Safety*	Adaptation
Rangachari and Woods (2020)	C	*	Healthcare	*International Journal of Environmental Research and Public Health*	Coping Adaptation
Ritz et al. (2015)	C	*	Safety	*International Journal of Environmental Research and Public Health*	Coping Adaptation
Salanova (2020)	C	*	Organizational psychology	*International Journal of Social Psychology*	Adaptation
Scholten et al. (2019)	E	Qualitative	Supply chain network	*Supply Chain Management-an International Journal*	Adaptation
Sengul et al. (2019)	E	Quantitative	Seveso (high- risk) industries (Turkey)	*Proceedings of the Institution of Mechanical Engineers Part O-Journal of Risk and Reliability*	No
Steen and Ferreira (2020)	E	Qualitative	Local authorities (Norway)	*Reliability Engineering and System Safety*	Adaptation
Tasic et al. (2020)	E	Qualitative and Quantitative	Security services (Southeast Asia)	*Journal of Risk Research*	Coping Adaptation
Ungar (2018)	C	*	Safety	*Ecology and Society*	Adaptation
van Trijp et al. (2018)	LR	*	Emergency response organizations	*International Journal of Emergency Management*	Adaptation
Wright et al. (2009)	E	Qualitative	Automotive (Asia)	*Asia Pacific Business Review*	No

**Methodology is not mentioned for conceptual articles and some review articles.*
***Context is not mentioned.*

41 empirical, 12 conceptual and 6 literature-review articles. The empirical articles use various types of data from different contexts; 19 use qualitative data, 13 apply quantitative data and six mixed methods; further, healthcare (13), universities (4), SMEs (5) and transport (4) are the dominant contexts. The articles were published in 45 different journals, in addition to

two book volumes and two conference/symposium proceedings; and no single journal dominates. The highest number of contributions within one journal was three, for *Reliability Engineering & System Safety*. The journals are located within many different fields, with business (11) predominant, followed by safety (7), learning (4) and healthcare (5). Regarding geographical context for the empirical studies, all continents are represented, with Europe dominant (19), followed by Australasia (6) and the USA (5).

Our review shows that learning is connected to resilience through the capabilities that organizations must possess and develop. Scholten et al. (2019) pointed out that "learning is ongoing across all stages of a disruption" (p. 439); we found that the same can be said about learning in the resilience stages. Our review shows that learning can prepare organizations for future events. Eight articles explicitly address *learning as part of the anticipation capability*. Overall, we see that anticipation refers to proactive action (Hardy, 2014; Duchek, 2020) where organizations detect "emerging problems" (Anderson et al., 2020, p. 2), "anticipate what could happen in an actual event" (Hermelin et al., 2020, p. 670) and then act on this. Adding experience to the organization's knowledge base is crucial, influencing how successful the organizational ability to anticipate further needs will be. Anticipation is dependent on the organizational ability to learn (Hillmann et al., 2018), which "guides and supports" (Ritz et al., 2015, p. 1868) advancement to the next stage of the resilience process: coping. Moreover, learning developed during this stage will inevitably influence capabilities developed in the two other stages (Anderson et al., 2020), and further improve organizational response. Nine articles explicitly address *learning as part of capabilities to cope* with uncertainty and sudden changes (Al-Atwi et al., 2021). We noted a tendency to address the role of learning in coping as a chance for organizations to expand their cognitive and behavioral perspectives (Tasic et al., 2020) and thus broaden the range of actions (Duchek, 2020) to build resilience to offer "better future protection" (Manfield and Newey, 2018, p. 1161). However, our study shows that the literature on OR learning is overwhelmingly concerned with adaptation capabilities. Altogether 38 articles explicitly include *learning as part of adaptation*, which could be explained by the fact that "adaptation may be what truly defines resilience" (Hardy, 2014). Learning is central to the adaptive capacity of an organization (Orth and Schuldis, 2021) and adaptability is held to be closely related to organizational learning (Bhaskara and Filimonau, 2021). Organizations must continuously absorb information and adapt to changes in the environment, in turn building on continuous learning (Battisti et al., 2019). Similarly, Crick and Bentley (2020) state that the interaction between absorbing information and the environment that can lead to adaptation is driven by learning; while Dutra et al. (2015) argue that adaptation occurs through learning and transmission of knowledge. In the context of developing organizational resilience, adaptation means more than simply getting the organization back to normal—it also involves developing capabilities to change and learn (Scholten et al., 2019; Duchek et al., 2020). As shown by Bragatto et al. (2021), building resilience involves more than just adapting disaster management plans: it also entails understanding and managing people's behavioral norms and mental models to help them unlearn behaviors which might have led to failure in the first place.

ANALYSIS OF FINDINGS

Our findings affirm and strengthen the link between Organizational Learning (OL) and Organizational Resilience (OR). Whereas, Pal et al. (2014) found that learning increased resilient performance, Nyman (2019) argued that learning is a "precondition for resilience". Mousa et al. (2020) have showed the role that organizational learning plays in predicting OR, while others, like Bhaskara and Filimonau (2021), highlight this relationship by arguing that *limited* organizational learning is a disadvantage for developing resilience: it is important to "aim at facilitating organizational learning" (p. 373). Our findings highlight the importance of identifying the determinants of OL in order to improve OR (Bhaskara and Filimonau, 2021); further, that resilience can be learned and therefore deliberately built (Manfield and Newey, 2018; Salanova, 2020). The identified main elements of OL for improving OR are appropriate management of experiential learning, a systemic approach to learning, the organizational ability to unlearn, and the existence of the context that facilitates organizational learning.

Learning From Experience

The importance of experiential learning has been heavily stressed in the OR literature (Hecht et al., 2019; Bragatto et al., 2021; Habiyaremye, 2021). Chand and Loosemore (2016) point out that such experience can be acquired during real events, training exercises and drills. Several authors address the important role of training and exercises (e.g., Chand and Loosemore, 2016; Adini et al., 2017; Khan et al., 2017; Hecht et al., 2019; Hermelin et al., 2020; Tasic et al., 2020; Bhaskara and Filimonau, 2021), including the post-exercise debriefing session as learning-promoting activities that will enhance OR. Moreover, OR may be improved by experience and learning from accidents, with a focus on clear communication and common training to share experiences from "accidents, fatalities and good practices" (Johnsen and Habrekke, 2009, p. 8). Both positive and negative *learning from own experiences* is crucial for showing how to increase positive outcomes and avoid negative ones (Anderson et al., 2020). *Learning from failures* is among the key capabilities of a resilient organization (Herbane, 2019; Bhaskara and Filimonau, 2021); further, some (e.g., Madsen and Desai, 2010, cited by Manfield and Newey, 2018) have argued that organizations can learn more from failure than success, particularly on the case of major failures. There are also important *lessons to be learned from successes* (Hardy, 2014; Hermelin et al., 2020) and from reflecting on positive outcomes. Scholten et al. (2019, p. 438) point out that organizations that do not "reflect on positive outcomes might inhibit organizations in seizing all the benefits of intentional experiential learning."

However, past *experiences may provide limited learning opportunities* (Bhaskara and Filimonau, 2021). Although experience can enable organizations to replay what has been

previously learned, they may fail "to prepare [. . .] for unforeseen and unpredicted events" (Elliott and Macpherson, 2010, p. 16). Established "best practices" may not be suitable for other crisis situations (Elliott and Macpherson, 2010, p. 16) and knowledge gained from one context cannot always be readily transferred to a different context: "coping with crisis cannot just be about deliberately acquiring a set of transmitted abilities, since to achieve competent practice depends on becoming better by doing" (Elliott and Macpherson, 2010, p. 6). The diverse nature of some events may also impede effective OL (Bhaskara and Filimonau, 2021). Past experiences may be codified into standard practices with "step-by-step" guidelines and operating procedures. However, such "codified learning" is problematic, as "the actual practice evolves as those in charge or involved in circumstances make sense of the ambiguous information, confused circumstances and incomplete data with which they are faced" (Elliott and Macpherson, 2010, p. 10). Therefore, codified learning can "only ever be partially successful" (Elliott and Macpherson, 2010, p. 11).

Another finding is the importance of *how experience is dealt with*. To ensure a true learning experience, acquired knowledge should be applied to real situations (Hillmann et al., 2018). Assuming that resilience is built through a combination of specific theoretical input and experiential learning, a combination will positively influence e.g., long-term learning and "thinking in complexity through imagining different futures" (Hillmann et al., 2018, p. 481). For example, extreme weather events have been found to "provide the best opportunities for experiential learning about how to improve hospital resilience to such events" and "embedding such experiences into hospital disaster management planning processes" (Chand and Loosemore, 2016, p. 885). Although crisis events have been subjected to extensive investigation, it is evident that organizations often fail to learn effectively, even when crises are regular events (Bhaskara and Filimonau, 2021). One contributing factor for this failure may be the fragmented nature of our understanding, and the resulting piecemeal conceptualization of the learning process (Elliott and Macpherson, 2010). For example, a disturbance may be familiar to the organization; but, due to bounded rationality, the need for new learning is not always identified, as organizations will often choose to fall back on old practices instead of developing new ones (Manfield and Newey, 2018). This results in lowered reintegration and internationalization of learning and reduced organizational resilience that stops being a growth experience (Manfield and Newey, 2018). Moreover, time lag and spatial distance may challenge the opportunity to learn from experience with a specific situation (Anderson et al., 2020). Therefore, improved organizational learning must involve *better understanding of the causes of accidents* (Johnsen and Habrekke, 2009), with a focus on triple-loop learning (Bragatto et al., 2021). It is not sufficient merely to collect reports of problems: organizations need to ensure that the reports are studied, and corrective actions implemented (Hardy, 2014). Another cause of unsuccessful OL is in confusing *learning* with *identifying lessons* (Elliott and Macpherson, 2010): "organizations often generate new knowledge (lessons learned) but fail to translate this knowledge into new behaviors" (Duchek, 2020, p. 231). It is important to recognize that lessons have not been learned until they are successfully implemented (Chand and Loosemore, 2016; Duchek, 2020).

Several authors highlight the value of organizations *learning from the practices and experiences of other organizations* (Gressgard and Hansen, 2015; Johannesen et al., 2020; Bhaskara and Filimonau, 2021; Fasey et al., 2021; Friday et al., 2021; Habiyaremye, 2021 as central to OL (Khan et al., 2017; Herbane, 2019). This may also spread further, to a whole network, as suppliers interact with each other, thereby also facilitating network resilience (Chen K. D. et al., 2021). Effective learning involves critical reflection at several levels, with effective communication and information sharing among the involved actors throughout the system (Johnsen and Habrekke, 2009; Dutra et al., 2015; Nicolletti et al., 2019). Such collaboration should "not only capture lessons learnt but also allow effective use and sharing of information across the multiple stakeholders involved in disaster planning" (Chand and Loosemore, 2016, p. 885). Our findings highlight the importance of a holistic approach to understanding this collective learning process among the many stakeholders involved in a disaster response (Bragatto et al., 2021). Lack of appropriate collaboration with other relevant stakeholders inhibits OL by depriving organizations of valuable opportunities to learn from others (Johnsen and Habrekke, 2009; Bhaskara and Filimonau, 2021). Moreover, learning from others may be inhibited by differing "resources, objectives and variations in learning experiences" between organizations (Friday et al., 2021, p. 262).

Importance of Continuity and Need for a System

Building resilience requires capturing and embodiment of learning into a capability (Hillmann et al., 2018). This in turn implies learning from adversity and codifying this learning into resilience capabilities against specific threats, thereby offering better future protection (Folke et al., 2004, cited by Manfield and Newey, 2018). Findings also demonstrate the importance of having *systems in place for organizational learning to happen,* and remaining continuous. Such systems must incorporate a range of learning practices that will ensure better reflection of experienced crises and as an outcome a more effective learning (Duchek et al., 2020). Organizations learn "in, from and for crisis" (Elliott and Macpherson, 2010, p. 3). To enhance OR, *learning has to be ongoing* (Chand and Loosemore, 2016; Bragatto et al., 2021), running across "the continuum of situations" from everyday practice to action during critical events (Hegde et al., 2020a, p. 75). Our findings emphasize that a resilient system continually learns, improves, and adjusts, even when stressed, and improves after a disturbance through adaptation (see also Hardy, 2014; Martinelli et al., 2018). In contrast to the results of other studies on *learning from near misses*, Azadegan et al. (2019) found that organizations "do learn significantly from such events" (p. 224). Further, when organizations experience near-misses, they consider long-term issues by "implementing procedural

response strategies" (Azadegan et al., 2019, p. 221), such as formal protocols, policies, and procedures, in contrast to theoretical suggestions that often indicate consideration of flexible strategies. Such procedural strategies are in line with double-loop learning, whereas flexible strategies are more in line with single-loop learning (Azadegan et al., 2019). Moreover, learning from accidents, or even more extreme events such as emergencies and catastrophes, needs to be integrated with learning from minor consequence events or even from the normal functioning of everyday activities (Hollnagel, 2011, cited by Patriarca et al., 2018, p. 267). The literature reviewed highlights how resilient learning is "ambidextrous," with a diversity of practices that organizations should explore and exploit (Al-Atwi et al., 2021), balancing flexible and procedural strategies (Azadegan et al., 2019).

Our findings also reveal emphasis on *the knowledge base*, and how knowledge is managed within the organization (see Elliott and Macpherson, 2010; Nicolletti et al., 2019; Anderson et al., 2020; Duchek, 2020; Duchek et al., 2020; Steen and Ferreira, 2020; Habiyaremye, 2021). Knowledge is generated through the stages of resilience—in other words, from the crisis event context that can create the need for change. Some authors hold that the organizational reaction to change is expressed by adaptation (Naimoli and Saxena, 2018; Fridell et al., 2020) so organizations must develop their capacity for change, which is predicated on the capacity for continuous learning (Morais-Storz and Nguyen, 2017). Adaptive learning is crucial to the ability to bounce back from adverse events that underlie crises (Habiyaremye, 2021). Therefore, we hold that learning is a mechanism for change which is needed in developing organizational resilience in the face of new problems (Anderson et al., 2020; Steen and Ferreira, 2020; Fasey et al., 2021). Knowledge, as the key antecedent of OR (Duchek, 2020), is also fundamental for resilient system performance irrespective of the activity in focus (Adini et al., 2017). It is, however, important to distinguish among sources of knowledge, as different sources are associated with different performance outcomes (Battisti et al., 2019).

To develop resilience, knowledge must remain in the organization, as employees may come and go (Dohaney et al., 2020). That being said, improved OL relies on the *feedback process* where individual lessons are shared collectively (Chand and Loosemore, 2016). Gressgard and Hansen (2015) argue that, for learning to contribute to building resilience, *diversity of opinions and perspectives is important*. Further, that *knowledge exchange between and across units in the organization* increases the ability to learn from failure, as compared to knowledge exchange within units. This highlights the need to *improve the feedback process* (Bragatto et al., 2021) and develop an *appropriate system for knowledge-sharing from the individual to the organizational level* (Bhaskara and Filimonau, 2021), relying on various practices (see e.g., Khan et al., 2017; Martinelli et al., 2018; Hegde et al., 2020a; Habiyaremye, 2021). This system should be based on trust and inclusion, to ensure efficient and appropriate communication (Rangachari and Woods, 2020). Moreover, organizations should develop processes and structures to utilize knowledge and implement this knowledge into future responses (Chand and Loosemore, 2016). In the absence of such systems, OR will remain "reactive (brittle) and restricted to the frontlines, with no way of advancing to team and organizational levels" (Rangachari and Woods, 2020, p. 6).

Dimensions of Learning Practices

Our findings also show that organizational learning is established through both formal and informal practices (see Gressgard and Hansen, 2015; Hecht et al., 2019; Hermelin et al., 2020; Orth and Schuldis, 2021)—and that formal practices are particularly associated with learning from failure (Hardy, 2014). Some studies find that formal practices ensure more thorough transfer of information, highlighting that disruption may undermine informal systems for knowledge exchange (Orth and Schuldis, 2021). Yet, our findings underscore the important role of informal practices—indicating that earlier analyses have been overly focused on formal rules and policies, and that new insights might emerge through a fuller examination of how informal organizational rules, norms and practices work (Bragatto et al., 2021). Finally, Chand and Loosemore (2016) note that informal organizational rules, norms, and practices may "undermine formal rules in determining... resilience" (p. 886).

With regard to the dimensions of learning, the literature reviewed for this study also focuses on investigating *how* lessons are learned and transferred among the various stakeholders (Bragatto et al., 2021) by examining the specific learning mechanisms that lead to differing resilient performance effects over time (Battisti et al., 2019). Taking as a starting point that learning is ongoing across all stages of a disruption [preparation (anticipation), response (coping) and recovery (adaptation)], Scholten et al. (2019) uncover six specific learning mechanisms and their nine antecedents for building supply-chain resilience. They place these mechanisms in two large categories associated with learning: intentional and unintentional. *Intentional* mechanisms are anticipative, situational, and vicarious learning. Anticipative learning takes place in anticipation of possible disruptions, aiming at knowledge transfer through formal training, education and collaboration; it results in the establishment of new routines or improvement of existing ones. Situational learning occurs during the coping stage, in the moment of disruption when organizations need to target the challenges that could have been anticipated but were not. Vicarious learning occurs during the adaption stage; it involves knowledge transfer based on the experiences and reflections of others. *Unintentional* learning mechanisms are processual, collaborative, and experiential learning. Processual learning occurs because of the proactive knowledge creation deduced from inherent organizational processes (e.g., changes in strategy, organizational growth, and operational refinement). Collaborative learning may occur during the response phase of disruption, when an immediate solution is needed, but procedures are lacking. Such instances may trigger collaboration and knowledge transfer across the actors involved. Experiential learning is associated with the recovery phase of disruption; it occurs through transfer of knowledge. Improved future performance relies heavily on rigorous and thorough learning from experience (Ellis and Shpielberg, 2003, cited by Scholten et al., 2019)—as highlighted above. The trap of retrospective simplification of experience (Christianson et al., 2009, cited by

Scholten et al., 2019) can be avoided by focusing on interpreting experience (Levinthal and March, 1993, cited by Scholten et al., 2019) instead of simplifying it. Finally, Scholten et al. (2019) highlight the largely overlooked value of unintentional learning.

The Role of Unlearning

OL is *a cyclical process consisting of unlearning and learning,* the "metamorphosis cycle" that is central to strategic resilience (Starbuck, 1967 p. 113, cited by Morais-Storz and Nguyen, 2017, p. 4). The deliberate process of unlearning can be approached as a stand-alone process (Fiol and O'Connor, 2017; Grisold et al., 2020), but it is a constituent component of this cycle (Tsang and Zahra, 2008, cited by Morais-Storz and Nguyen, 2017). The importance of unlearning has received particular attention in the literature on OR (Morais-Storz and Nguyen, 2017; Orth and Schuldis, 2021). Unlearning is associated with "a process of getting rid of certain things from an organization" (Tsang and Zahra, 2008, p. 1437), often triggered by crisis (Fiol and O'Connor, 2017) that requires organizations to adopt new ways of thinking and abandon old mental models and processes (Duchek, 2020). In a world of turbulence and uncertainty, organizations are expected to act proactively, before action is desperately needed, through their own continual transformation (Morais-Storz and Nguyen, 2017). Organizations must be able to identify the early warning signs of when action is needed, as shown through a "web of symptoms" (Baer et al., 2013, p. 199; Morais-Storz and Nguyen, 2017). Ideally, new learning should be created before the need for change has become desperately obvious (Morais-Storz and Nguyen, 2017).

Learning and unlearning are mutually supportive in creating knowledge and organizational learning (Morais-Storz and Nguyen, 2017). The most important role of unlearning is to clear away obstacles created from misleading knowledge and obsolete routines, so as to pave the way for future learning, but unlearning can also aid the effective acquisition of new understandings (Fiol and O'Connor, 2017; Grisold et al., 2020). For most organizations, learning is impossible without unlearning: it is in fact the precondition for new learning, enhancing the effectiveness of learning in a process of change. It has been proposed that the greater the capacity for unlearning capability, the stronger may the positive effect of OL on OR be (Orth and Schuldis, 2021). The metamorphosis cycle is driven by these two processes, organizational unlearning capability exerting a positive moderating effect on the relationship between organizational learning and organizational resilience (Orth and Schuldis, 2021).

Context for Learning

Our review findings underscore the importance of context, to share and "capture the relevant information and to create a social learning process" (Prasad et al., 2015, p. 454) where individuals are committed and motivated to learn, to achieve improved OL (Gilson et al., 2020). The main function of this context, necessary within and between organizations, is to support OL (Naimoli and Saxena, 2018). While organizations learn from their own activities as well as from other organizations activities, there is also a question of different contexts for learning different knowledge. Given the nature and demands of adversity, the context also needs to be active— "not necessarily fully controlled and sequential, but instead open to innovative ways of tackling open problems" (Hermelin et al., 2020, p. 670).

Reflecting on the complexity of context (see Argote and Miron-Spektor, 2011) our review has identified some contextual components that affect learning. Central here is the role of leadership. Attentive leadership and the wellbeing of employees is seen as "the core of learning and culture" (Pal et al., 2014, p. 418). "Listening, being respectful, allowing others to lead and creating spaces for learning from experience are important practices of leadership in complexity and for resilience" (Belrhiti et al., 2018; Petrie and Swanson, 2018, cited by Gilson et al., 2020, p. 9). Associated with leadership are empowerment and role clarity that enable the extraction, distribution, and application of information "from failures made in various parts of the organizational system;" they are important to *knowledge-exchange* and are thus related to creating a context for learning from failure (Gressgard and Hansen, 2015, p. 173). Further, organizations need to be able to take in new information and reflect on experiences, in order to cope and adapt to situations of adversity (Orth and Schuldis, 2021). Aspiring to learn and improve entails organizational desire to accept risk and failure, as both are inherent precursors of OL (Fasey et al., 2021). Such exchange can be facilitated though enhanced work engagement and an open collaborative work climate (Fasey et al., 2021). This in turn relies on leadership involvement and requires a more *organic structure;* where employees feel "responsible for the organization's development, they are more likely open to change" (Duchek, 2020, p. 237).

The findings indicate that *organizational resistance to change* has been noted as the main impediment to organizational transformation, and consequently to successful learning (Hardy, 2014). Such resistance can be found in individuals and in organizations (Donahue and Tuohy, 2006, cited by Hardy, 2014). Within organizations, *"change fatigue"* and lack of employee motivation may inhibit learning (Manfield and Newey, 2018, p. 1171). Motivation for learning is important (Gilson et al., 2020), but so are other aspects like policy and administrative demands, often in combination with resource constraints (Naimoli and Saxena, 2018) and the cost of studying reports and implementing actions (Hardy, 2014). Learning from other organizations may be inhibited by "resources, objectives and variations in learning experiences" between organizations (Friday et al., 2021, p. 262).

Summary of the Analysis

In sum, our findings indicate that OL is essential to OR. However, the role of learning varies, depending on which stage of the resilience process is in focus. The frequent use of learning in relation to adaptation as opposed to anticipation and coping shows that learning is especially important in this resilience stage. However, as **Table 1** shows, learning is also addressed in the two latter stages; and, as underlined by several authors, it is a central part of overall resilience. Resilience can be built by improving the effectiveness of learning. Our results indicate that experiential learning is central to how organizations gain and expand knowledge in order to improve their capabilities. Effective OL

relies on a system to ensure its continuity, knowledge-transfer across organizational levels, with organizational processes that allow for formal as well as informal practices. Our review has also shown that unlearning is necessary to facilitate and adopt new and updated learning, thereby ensuring further growth toward OR. Finally, effective learning requires a supportive context.

DISCUSSION

Our review shows that OR is becoming an important goal for various types of organizations regarding crisis management, but most of all, improved performance in a world of high uncertainty. The dominance of qualitative data may be interpreted as a sign of this being a relatively young field of research. Further, it seems reasonable for empirical studies from high-risk industries like healthcare and transport dominate the field. Interestingly, however, also other fields, like tourism, food, retail, public administration and universities, also are represented as empirical fields. We interpret this as a sign of the growing interest in improving organizational performance under conditions of adversity in all branches and sectors because of the increased global threat picture. The representation of all continents as geographical contexts, and the high number of recent articles (46 out of 59 published the between 2017 and 2021) shows the growing interest in the connection between OR and OL as an emerging field of research worldwide.

Despite some variation in how explicit the studies examined here are in their use of terminology, our review clearly shows the fundamental role of OL in building OR. Some articles specify and highlight learning in connection to anticipation, coping or adaptation; others do not. Regardless, learning is still implicitly present and arguably crucial for improving performance and developing OR. Yet, the literature on resilience would stand to benefit from addressing learning *more directly*, rather than as implicit, or in "broad terms only" (Battisti et al., 2019, p. 39). In this study, we have focused on the capabilities underlying the above mentioned stages of resilience—specifically on learning as a means for building them. Our findings show that adaptation is recognized as vital for resilience, but that goes for learning as well, as it facilitates the development of the other resilience stages and capabilities. Just as OL relies on multiple levels of interactions within and outside an organization so does OR. The frequent use of learning in relation to the adaptation stage, in comparison to the anticipation and coping stages, shows that learning is especially important in this stage of OR.

From our findings on how learning is addressed in the literature on resilience, we argue that the dynamic nature of learning in resilience is particularly evident in the conceptualizations of coping. Organizations learn "in, from and for crisis" (Elliott and Macpherson, 2010, p. 3) and cope by using past experience (both positive and negative) and knowledge to manage current situations. The interaction between coping and the two other stages of resilience can be said to be strongly driven by learning. In turn, this implies that the capabilities that belong to other stages will be strengthened simultaneously. We hold that organizations can build resilience by focusing on improving their ability to learn. We find it reasonable to suggest that it may be advantageous for organizations to focus on their learning processes in daily organizational life, not only during disturbances and crisis events, if they wish to strengthen resilience.

Our review indicates that *learning deserves greater emphasis in relation to how organizations can develop resilience*. It also highlights the importance of identifying the determinants of OL in order to build OR. By elaborating the various facets of OL in OR, the value of informal and unintentional learning processes, the need for a system, contextual factors, and the focus on unlearning, our findings and analysis contribute with deeper insights to this field of study also reflecting on the complexity of OL interactions stated in theory. OR is indeed enhanced by facilitating OL, but many aspects influence how effective that learning will be. In practice this implies that organizations may improve learning by first identifying where there is a need for changing their practices and routines.

This study has affirmed and further nuanced OL as intentional and unintentional processes highlighting of the overlooked value of unintentional learning in particular. Effective OL is a matter of transforming relevant knowledge into practice including the transformation of "unintentional learning into explicit learning" (Scholten et al., 2019, p. 439). However, unintentional learning might, in fact, require more from the organization in terms of flexibility and attentiveness, to be able to recognize the learning opportunities that can improve performance and create appropriate systems for knowledge transfer. These intentional and unintentional learning processes are closely linked to the discussion of formal and informal learning practices. Practices that focus heavily on formal rules and learning policies are criticized, and the value of analyzing informal organizational rules, norms and practices is highlighted. Recognition of the importance of *unlearning* is an aspect of the connection between OL and OR that was not included in our theoretical framework. This constitutes one of the most important contributions of our study. Unlearning in developing OR involves abandoning old mental constructs in favor of new, more relevant ones—which in turn implies that organizations must identify which of their current practices and routines obstruct growth, to pave the way for necessary changes. Our findings show that double-loop and triple-loop learning are especially crucial for developing OR. This deeper learning is necessary to avoid pitfalls that hinder effective learning. Further, improved OL depends on a better understanding of root causes of events, with consideration given to long-term issues as opposed to correcting errors. We also found that focusing on learning processes (triple-loop learning), by establishing processes and routines appropriate for learning specific, relevant lessons can foster the development of OR.

We argue that effective learning is facilitated through a learning system that captures the diverse nature of learning practices that are both flexible but also embedded in organizational routines relying on formal protocols, policies, and procedures. A main finding is that such a system is critical for developing OR because learning must be transformed

into resilience capabilities. Moreover, a system for effective learning must facilitate communication and allow knowledge, experiences, opinions, and perspectives to be shared, both within and across organizations and stakeholders. We point out that collective inter-organizational learning is central to OR.

Limitations

One *limitation* of this article concerns the risk of failing to identify relevant contributions during the sampling stage and/or excluding some during the analytical screening process. Moreover, several important contributions have been published after May 2021. The amount of data in the 59 selected articles is huge and the scope of this article limited, so several interesting findings have had to be omitted. Thus, our selection of what to include constitutes another limitation. There is a further risk of missing something, or misinterpreting the findings, during the analytical cycles of the coding process. There exist various OR frameworks; we have chosen the one proposed by Duchek (2020), but it might be that other frameworks would address OL differently. Learning is truly an inherent part of OR; and, as our focus has been on learning as part of resilience, we have not delved into the various frameworks for OR. We acknowledge the variations of terms and concepts employed to conceptualize resilience, such as *monitoring* and *responding* (Adini et al., 2017; Anderson et al., 2020), but here we have emphasized what the terms and concept capture and express in terms of *learning*. We have not addressed the complexity of OL, which, however, should be clear from our data on aspects of unlearning and intended/unintended learning. Finally, we recognize the synergy between OR and OL (Vogus and Sutcliffe, 2007; Lombardi et al., 2021; Rodríguez-Sánchez et al., 2021) the scope of this article has been limited to how OL influences OR; the reverse effect has remained unexplored.

CONCLUSION

To our knowledge this is the first review to focus solely on the relationship between organizational learning and resilience, a relationship that has been discussed and established by scholars from various fields. More work is needed on how organizations can improve their learning abilities, as learning is essential for organizations to evolve from one resilience stage to another. OR can indeed be learned, so effective learning can serve as a critical driver for building OR. The effectiveness of OL can be increased by a more comprehensive understanding of the link between experiences and improved performance, with more focus on the value of diversity. OR is dependent upon an appropriate system to ensure continuous, inclusive, purposeful OL, capable of facilitating intentional and unintentional learning, and supported by an active context that enables new knowledge to enter the picture. Effective OL toward OR also requires the ability to unlearn previous ways of doing things, to learn and engage in new and improved ways of response. Lastly, organizations do not exist in a vacuum. OL must involve collaboration between organizations, to ensure sharing and exchange of valuable knowledge and experience, to build OR.

This article has theoretical and practical implications. As regards theory, our study contributes with insights on why learning is so central to resilience, through all the stages of capability. Our findings shed light on how learning can be targeted more effectively and how it can facilitate resilience. Second, our work shows the role of unlearning in OR, a point that deserves more attention in further research. In terms of theory, this study offers further insights into aspects of learning from experience and how this should be managed to build resilient organizations. On a practical note, there is still a need for empirical verification of the effects of learning on OR. More understanding is also needed of how learning interacts over time with other multilevel processes that contribute to building OR. Our findings have made clear the importance of establishing a system where organizations can build on the experiences and knowledge of other organizations in building resilience.

Our review also reveals need for *further research*. Current understanding of the dynamics of effective learning is at a very early stage, so more investment in systematic research on learning in organizations and their link to resilience-building (Naimoli and Saxena, 2018) is called for. Further, there is a need for better understanding the correlation, if any, between disastrous events, their driving hazards, and major consequences; how learning occurs in affected organizations, and how long this organizational learning lasts (Bhaskara and Filimonau, 2021, p. 366). A key gap involves the scant attention given to the processes of knowledge transfer (Elliott and Macpherson, 2010). Also needed is a deeper understanding of how learning interacts over time with other multilevel processes that contribute to building OR (Fasey et al., 2021). Since learning is central if organizations are to evolve from one resilience stage to another, this review reveals the need for more research on how organizations can improve their learning abilities in general. More research, preferably empirical, is needed on the role, and potential, of informal practices and unintentional learning processes to improve OL related to OR, and on the role and practices of unlearning. Our study has also revealed the need for more research on the link between OL and learning at the individual, group and interorganizational levels. Even if it may seem paradoxical to "organize" for informal and unintended processes, this links in with the need for continuity and a coherent learning system.

AUTHOR CONTRIBUTIONS

LE and MS conceptualized the article and coded and analyzed the material. MS provided the analytical framework. LE performed the data sampling, organized the material, and performed the first round of coding. AG provided **Table 1** and contributed with critical editing of the whole manuscript. All authors contributed in the screening process, analytical stage with writing and critical editing, and have approved the submitted text.

REFERENCES

Adini, B., Cohen, O., Eide, A. W., Nilsson, S., Aharonson-Daniel, L., and Herrera, I. A. (2017). Striving to be resilient: what concepts, approaches and practices should be incorporated in resilience management guidelines? *Technol. Forecast. Soc. Change* 121, 39–49. doi: 10.1016/j.techfore.2017.01.020

Al-Atwi, A. A., Amankwah-Amoah, J., and Khan, Z. (2021). Micro-foundations of organizational design and sustainability: the mediating role of learning ambidexterity. *Int. Bus. Rev.* 30, 11. doi: 10.1016/j.ibusrev.2019.101656

Andersen, E. (2016). *Learning to learn. Harvard Buisness Review*, 94. Available online at: https://hbsp.harvard.edu/product/R1603J-PDF-ENG (accessed December 12, 2021).

Anderson, J. E., Ross, A. J., Macrae, C., and Wiig, S. (2020). Defining adaptive capacity in healthcare: a new framework for researching resilient performance. *Appl. Ergon.* 87, 9. doi: 10.1016/j.apergo.2020.103111

Annarelli, A., Battistella, C., and Nonino, F. (2020). A Framework to evaluate the effects of organizational resilience on service quality. *Sustainability* 12, 958. doi: 10.3390/su12030958

Antonacopoulou, E., and Chiva, R. (2007). The social complexity of organizational learning: the dynamics of learning and organizing. *Manage. Learn.* 38, 277–295. doi: 10.1177/1350507607079029

Antonacopoulou, E. P., and Sheaffer, Z. (2014). Learning in crisis:rethinking the relationship between organizational learning and crisis management. *J. Manage. Inquiry* 23, 5–21. doi: 10.1177/1056492612472730

Argote, L. (2011). Organizational learning research: past, present and future. *Manage. Learn.* 42, 439–446. doi: 10.1177/1350507611408217

Argote, L., and Ingram, P. (2000). Knowledge transfer: a basis for competitive advantage in firms. *Organ. Behav. Hum. Decis. Process.* 82, 150–169. doi: 10.1006/obhd.2000.2893

Argote, L., Lee, S., and Park, J. (2020). Organizational learning processes and outcomes: major findings and future research directions. *Manage. Sci.* 67, 5399–5429. doi: 10.1287/mnsc.2020.3693

Argote, L., and Miron-Spektor, E. (2011). Organizational learning: from experience to knowledge. *Organization Sci.* 22, 1123–1137. doi: 10.1287/orsc.1100.0621

Argote, L., and Todorova, G. (2007). "Organizational learning: review and future directions," in *International Review of Industrial and Organizational Psychology*, editors G. P. Hodgkinson and J. K. Ford (New York, Ny: John Wiley & Sons Ltd), 193–234.

Argyris, C. (2002). Double-loop learning, teaching, and research. *Acad. Manage. Learn. Educ.* 1, 206–218. doi: 10.5465/amle.2002.8509400

Argyris, C., and Schön, D. A. (1978). *Organizational Learning: A Theory of Action Perspective*. Reading, MA: Addison-Wesley.

Argyris, C., and Schön, D. A. (1996). *Organizational Learning II: Theory, Method and Practice.* Reading, MA: Addison-Wesley.

Azadegan, A., Srinivasan, R., Blome, C., and Tajeddini, K. (2019). Learning from near-miss events: an organizational learning perspective on supply chain disruption response. *Int. J. Prod. Econ.* 216, 215–226. doi: 10.1016/j.ijpe.2019.04.021

Baer, M., Dirks, K. T., and Nickerson, J. A. (2013). Microfoundations of strategic problem formulation. *Strategic Manage. J.* 34, 197–214. doi: 10.1002/smj.2004

Baker, W. E., and Sinkula, J. M. (1999). The synergistic effect of market orientation and learning orientation on organizational performance. *J. Acad. Mark. Sci.* 27, 411. doi: 10.1177/0092070399274002

Battisti, M., Beynon, M., Pickernell, D., and Deakins, D. (2019). Surviving or thriving: the role of learning for the resilient performance of small firms. *J. Bus. Res.* 100, 38–50. doi: 10.1016/j.jbusres.2019.03.006

Belrhiti, Z., Nebot Geralt, A., and Marchal, B. (2018). Complex leadership in healthcare: a scoping review. *Int. J. Health Policy Manage.* 7, 1073–1084. doi: 10.15171/ijhpm.2018.75

Bhaskara, G. I., and Filimonau, V. (2021). The COVID-19 pandemic and organisational learning for disaster planning and management: a perspective of tourism businesses from a destination prone to consecutive disasters. *J. Hosp. Tourism Manage.* 46, 364–375. doi: 10.1016/j.jhtm.2021.01.011

Boin, A., Comfort, L. K., and Demchak, C. C. (2010). "The rise of resilience," in *Designing Resilience: Preparing for Extreme Events*, editors L. K. Comfort, A. Boin, and C. C. Demchak (Pittsburgh, Pennsylvania: University of Pittsburgh Press).

Boin, A., and Lodge, M. (2016). Designing Resilient Institutions for transboundary crisis management: a time for public administration. *Public Adm.* 94, 289–298. doi: 10.1111/padm.12264

Boin, A., and van Eeten, M. J. G. (2013). The resilient organization. *Public Manage. Rev.* 15, 429–445. doi: 10.1080/14719037.2013.769856

Boyatzis, R. E. (1998). *Transforming Qualitative Information: Thematic Analysis and Code Development*. Thousand Oaks, CA: Sage Publications, Inc.

Bragatto, P., Vairo, T., Milazzo, M. F., and Fabiano, B. (2021). The impact of the COVID-19 pandemic on the safety management in Italian Seveso industries. *J. Loss Prevent. Process Ind.* 70, 104393. doi: 10.1016/j.jlp.2021.104393

Braun, V., and Clarke, V. (2006). Using thematic analysis in psychology. *Qual. Res. Psychol.* 3, 77–101. doi: 10.1191/1478088706qp063oa

Britt, T. W., Shen, W., Sinclair, R. R., Grossman, M. R., and Klieger, D. M. (2016). How Much do we really know about employee resilience? *Ind. Organ. Psychol.* 9, 378–404. doi: 10.1017/iop.2015.107

Chand, A. M., and Loosemore, M. (2016). Hospital learning from extreme weather events: using causal loop diagrams. *Build. Res. Inform.* 44, 875–888. doi: 10.1080/09613218.2016.1097805

Chen, K. D., Li, Y. H., and Linderman, K. (2021). Supply network resilience learning: an exploratory data analytics study. *Decision Sci.* 20, 1–20. doi: 10.1111/deci.12513

Chen, R., Xie, Y., and Liu, Y. (2021). Defining, conceptualizing, and measuring organizational resilience: a multiple case study. *Sustainability* 13, 2517. doi: 10.3390/su13052517

Chiva, R., Ghauri, P., and Alegre, J. (2014). Organizational learning, innovation and internationalization: a complex system model. *Br. J. Manage.* 25, 687–705. doi: 10.1111/1467-8551.12026

Christianson, M. K., Farkas, M. T., Sutcliffe, K. M., and Weick, K. E. (2009). Learning through rare events: significant interruptions at the Baltimore & Ohio Railroad Museum. *Organization Sci.* 20, 846–860. doi: 10.1287/orsc.1080.0389

Cook, S. D. N., and Yanow, D. (1993). Culture and organizational learning. *J. Manage. Inquiry* 2, 373–390. doi: 10.1177/105649269324010

Cooper, H. M. (1988). Organizing knowledge syntheses: a taxonomy of literature reviews. *Knowledge Soc.* 1, 104. doi: 10.1007/BF03177550

Crick, R., and Bentley, J. (2020). Becoming a resilient organisation: integrating people and practice in infrastructure services. *Int. J. Sustain. Eng.* 13, 423–440. doi: 10.1080/19397038.2020.1750738

Crossan, M. M., and Apaydin, M. (2010). A multi-dimensional framework of organizational innovation: a systematic review of the literature. *J. Manage. Stud.* 47, 1154–1191. doi: 10.1111/j.1467-6486.2009.00880.x

Crossan, M. M., Lane, H. W., and White, R. E. (1999). An organizational learning framework: from intuition to institution. *Acad. Manage. Rev.* 24, 522–537. doi: 10.2307/259140

Dohaney, J., de Roiste, M., Salmon, R. A., and Sutherland, K. (2020). Benefits, barriers, and incentives for improved resilience to disruption in university teaching. *Int. J. Disaster Risk Reduct.* 50, 9. doi: 10.1016/j.ijdrr.2020.101691

Donahue, A., and Tuohy, R. (2006). Lessons we don't learn: a study of the lessons of disasters, why we repeat them, and how we can learn them. *Homeland Security Affairs* 2, 4. Available online at: https://www.hsaj.org/articles/167 (accessed December 10, 2021).

Duchek, S. (2020). Organizational resilience: a capability-based conceptualization. *Bus. Res.* 13, 215–246. doi: 10.1007/s40685-019-0085-7

Duchek, S., Raetze, S., and Scheuch, I. (2020). The role of diversity in organizational resilience: a theoretical framework. *Bus. Res.* 13, 387–423. doi: 10.1007/s40685-019-0084-8

Dutra, L. X. C., Bustamante, R. H., Sporne, I., van Putten, I., Dichmont, C. M., Ligtermoet, E., et al. (2015). Organizational drivers that strengthen adaptive capacity in the coastal zone of Australia. *Ocean Coast. Manag.* 109, 64–76. doi: 10.1016/j.ocecoaman.2015.02.008

Ekstedt, M., and Odegard, S. (2015). Exploring gaps in cancer care using a systems safety perspective. *Cogn. Technol. Work* 17, 5–13. doi: 10.1007/s10111-014-0311-1

Elliott, D., and Macpherson, A. (2010). Policy and practice: recursive learning from crisis. *Group Org. Manage.* 35, 572–605. doi: 10.1177/1059601110383406

Ellis, S., and Shpielberg, N. (2003). Organizational learning mechanisms and managers' perceived uncertainty. *Hum. Relat.* 56, 1233–1254. doi: 10.1177/00187267035610004

Fannoun, S., and Kerins, J. (2019). Towards organisational learning enhancement: assessing software engineering practice. *Learn. Org.* 26, 44–59. doi: 10.1108/TLO-09-2018-0149

Fasey, K. J., Sarkar, M., Wagstaff, C. R. D., and Johnston, J. (2021). Defining and characterizing organizational resilience in elite sport. *Psychol. Sport Exerc.* 52, 12. doi: 10.1016/j.psychsport.2020.101834

Fiol, M., and O'Connor, E. (2017). Unlearning established organizational routines – Part I. *Learn. Org.* 24, 13–29. doi: 10.1108/TLO-09-2016-0056

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., et al. (2004). Regime shifts, resilience, and biodiversity in ecosystem management. *Annu. Rev. Ecol. Evol. Syst.* 35, 557–581. doi: 10.1146/annurev.ecolsys.35.021103.105711

Friday, D., Savage, D. A., Melnyk, S. A., Harrison, N., Ryan, S., and Wechtler, H. (2021). A collaborative approach to maintaining optimal inventory and mitigating stockout risks during a pandemic: capabilities for enabling health-care supply chain resilience. *J. Hum. Logistics Supply Chain Manage.* 11, 24. doi: 10.1108/JHLSCM-07-2020-0061

Fridell, M., Edwin, S., von Schreeb, J., and Saulnier, D. D. (2020). Health system resilience: what are we talking about? A scoping review mapping characteristics and keywords. *Int. J. Health Policy Manage.* 9, 6–16. doi: 10.15171/ijhpm.2019.71

Garvin, D. A. (1993). Building a learning organization. *Harv. Bus. Rev.* 71, 78–91.

Garvin, D. A., Edmondson, A. C., and Gino, F. (2008). Is yours a learning organization? *Harvard Bus. Rev.* 86, 109–116, 134. Available online at: https://hbr.org/2008/03/is-yours-a-learning-organization (accessed December 5, 2021).

Gherardi, S. (2008). "Situated knowledge and situated action: What do practice-based studies promise?," in *The SAGE Handbook of New Approaches in Management and Organization*, editors D. Barry and H. Hansen (Los Angeles, CA: Sage), 516–525.

Gherardi, S., and Nicolini, D. (2002). Learning in a constellation of interconnected practices: canon or dissonance? *J. Manage. Stud.* 39, 419–436. doi: 10.1111/1467-6486.t01-1-00298

Gherardi, S., Nicolini, D., and Odella, F. (1998). Toward a social understanding of how people learn in organizations:the notion of situated curriculum. *Manage. Learn.* 29, 273–297. doi: 10.1177/1350507698293002

Gilson, L., Ellokor, S., Lehmann, U., and Brady, L. (2020). Organizational change and everyday health system resilience: lessons from Cape Town, South Africa. *Soc. Sci. Med.* 266, 10. doi: 10.1016/j.socscimed.2020.113407

Giustiniano, L., Clegg, S. R., Cunha, M. P., and Rego, A. (2018). *Elgar Introduction to Theories of Organizational Resilience*. Cheltenham, UK: Edward Elgar Publishing. doi: 10.4337/9781786437044

Gressgard, L. J., and Hansen, K. (2015). Knowledge exchange and learning from failures in distributed environments: the role of contractor relationship management and work characteristics. *Reliab. Eng. Syst. Saf.* 133, 167–175. doi: 10.1016/j.ress.2014.09.010

Grisold, T., Klammer, A., and Kragulj, F. (2020). Two forms of organizational unlearning: insights from engaged scholarship research with change consultants. *Manage. Learn.* 51, 598–619. doi: 10.1177/1350507620916042

Habiyaremye, A. (2021). Co-operative learning and resilience to COVID-19 in a small-sized South African enterprise. *Sustainability* 13, 17. doi: 10.3390/su13041976

Hardy, T. L. (2014). "Resilience: a holistic safety approach," in *2014 60th Annual Reliability and Maintainability Symposium* (New York).

Hecht, A. A., Biehl, E., Barnett, D. J., and Neff, R. A. (2019). Urban food supply chain resilience for crises threatening food security: a qualitative study. *J. Acad. Nutr. Diet.* 119, 211–224. doi: 10.1016/j.jand.2018.09.001

Hegde, S., Hettinger, A. Z., Fairbanks, R. J., Wreathall, J., Krevat, S. A., and Bisantz, A. M. (2020a). Knowledge elicitation to understand resilience: a method and findings from a health care case study. *J. Cogn. Eng. Decis. Mak.* 14, 75–95. doi: 10.1177/1555343419877719

Hegde, S., Hettinger, A. Z., Fairbanks, R. J., Wreathall, J., Krevat, S. A., Jackson, C. D., et al. (2020b). Qualitative findings from a pilot stage implementation of a novel organizational learning tool toward operationalizing the Safety-II paradigm in health care. *Appl. Ergon.* 82, 8. doi: 10.1016/j.apergo.2019.102913

Herbane, B. (2019). Rethinking organizational resilience and strategic renewal in SMEs. *Entrepreneurship Regional Dev.* 31, 476–495. doi: 10.1080/08985626.2018.1541594

Hermelin, J., Bengtsson, K., Woltjer, R., Trnka, J., Thorstensson, M., Pettersson, J., et al. (2020). Operationalising resilience for disaster medicine practitioners: capability development through training, simulation and reflection. *Cogn. Technol. Work* 22, 667–683. doi: 10.1007/s10111-019-00587-y

Hernes, T., and Irgens, E. J. (2013). Keeping things mindfully on track: organizational learning under continuity. *Manage. Learn.* 44, 253–266. doi: 10.1177/1350507612445258

Hillmann, J., Duchek, S., Meyr, J., and Guenther, E. (2018). Educating future managers for developing resilient organizations: the role of scenario planning. *J. Manage. Educ.* 42, 461–495. doi: 10.1177/1052562918766350

Hillmann, J., and Guenther, E. (2021). Organizational resilience: a valuable construct for management research? *Int. J. Manag. Rev.* 23, 7–44. doi: 10.1111/ijmr.12239

Hollnagel, E. (2011). "Prologue: the scope of resilience engineering," in *Resilience Engineering in Practice: A Guidebook*, editors E. Hollnagel, J. Pariès, D. Woods, and J. Wreathall (England: Surrey: Taylor & Francis Group), 30–41.

Huber, G. P. (1991). Organizational learning: the contributing processes and the literatures. *Org. Sci.* 2, 88–115. doi: 10.1287/orsc.2.1.88

Johannesen, D. T. S., Lindoe, P. H., and Wiig, S. (2020). Certification as support for resilience? Behind the curtains of a certification body: a qualitative study. *BMC Health Serv. Res.* 20, 14. doi: 10.1186/s12913-020-05608-5

Johnsen, S. O., and Habrekke, S. (2009). *Can Organisational Learning Improve Safety and Resilience During Changes?* Boca Raton: Crc Press-Taylor & Francis Group.

Johnsen, S. O., and Stene, T. (2014). *Improving Human Resilience in Space and Distributed Environments by CRIOP. Boca* Raton: CRC, FL Press/Taylor & Francis Group.

Jones, O., and Macpherson, A. (2006). Inter-organizational learning and strategic renewal in SMEs: extending the 4I framework. *Long Range Plann.* 39, 155–175. doi: 10.1016/j.lrp.2005.02.012

Kayes, D. C. (2015). *Organizational Resilience: How Learning Sustains Organizations in Crisis, Disaster, and Breakdown*. Oxford: Oxford University Press.

Khan, S. J., Deere, D., Leusch, F. D. L., Humpage, A., Jenkins, M., Cunliffe, D., et al. (2017). Lessons and guidance for the management of safe drinking water during extreme weather events. *Environ. Sci. Water Res. Technol.* 3, 262–277. doi: 10.1039/C6EW00165C

Khan, T. Z. A., Farooq, W., and Rasheed, H. (2019). Organizational resilience: a dynamic capability of complex systems. *J. Manage. Res.* 6, 1–26. doi: 10.29145//JMR/61/0601001

Klockner, K., and Meredith, P. (2020). Measuring resilience potentials: a pilot program using the resilience assessment grid. *Safety* 6, 17. doi: 10.3390/safety6040051

Kugley, S., Wade, A., Thomas, J., Mahood, Q., Jørgensen, A.-M. K., Hammerstrøm, K., et al. (2017). Searching for studies: a guide to information retrieval for Campbell systematic reviews. *Campbell Syst. Rev.* 13, 1–73. doi: 10.4073/cmg.2016.1

Lave, J., and Wenger, E. (1991). *Situated Learning: Legitimate Peripheral Participation*. Cambridge: Cambridge University Press.

Lavie, D., Stettner, U., and Tushman, M. L. (2010). Exploration and exploitation within and across organizations. *Acad. Manag. Ann.* 4, 109–155. doi: 10.5465/19416521003691287

Lawrence, T. B., Mauws, M. K., Dyck, B., and Kleysen, R. F. (2005). The politics of organizational learning: integrating power into the 4I framework. *Acad. Manage. Rev.* 30, 180–191. doi: 10.5465/amr.2005.15281451

Lengnick-Hall, C. A., Beck, T. E., and Lengnick-Hall, M. L. (2011). Developing a capacity for organizational resilience through strategic human resource management. *Hum. Resource Manage. Rev.* 21, 243–255. doi: 10.1016/j.hrmr.2010.07.001

Levinthal, D. A., and March, J. G. (1993). The myopia of learning. *Strategic Manage. J.* 14, 95–112. doi: 10.1002/smj.4250141009

Liñán, F., and Fayolle, A. (2015). A systematic literature review on entrepreneurial intentions: citation, thematic analyses, and research agenda. *Int. Entrepreneurship Manage. J.* 11, 907–933. doi: 10.1007/s11365-015-0356-5

Linnenluecke, M., and Griffiths, A. (2010). Beyond adaptation: resilience for business in light of climate change and weather extremes. *Bus. Soc.* 49, 477–511. doi: 10.1177/0007650310368814

Linnenluecke, M. K. (2017). Resilience in business and management research: a review of influential publications and a research agenda. *Int. J. Manag. Rev.* 19, 4–30. doi: 10.1111/ijmr.12076

Lipshitz, R., Popper, M., and Friedman, V. J. (2002). A multifacet model of organizational learning. *J. Appl. Behav. Sci.* 38, 78–98. doi: 10.1177/0021886302381005

Lombardi, S., Pina e Cunha, M., and Giustiniano, L. (2021). Improvising resilience: the unfolding of resilient leadership in COVID-19 times. *Int. J. Hosp. Manage.* 95, 102904. doi: 10.1016/j.ijhm.2021.102904

Lundberg, C. C. (1995). Learning in and by organization: three conceptual issues. *Int. J. Org. Anal.* 3, 10–23. doi: 10.1108/eb028821

Ma, Z. Z., Xiao, L., and Yin, J. L. (2018). Toward a dynamic model of organizational resilience. *Nankai Bus. Rev. Int.* 9, 246–263. doi: 10.1108/NBRI-07-2017-0041

Mackay, D., and Zundel, M. (2017). Recovering the divide: a review of strategy and tactics in business and management. *Int. J. Manag. Rev.* 19, 175–194. doi: 10.1111/ijmr.12091

Madsen, P. M., and Desai, V. (2010). Failing to learn? The effects of failure and success on organizational learning in the global orbital launch vehicle industry. *Acad. Manage. J.* 53, 451–476. doi: 10.5465/amj.2010.51467631

Manfield, R. C., and Newey, L. R. (2018). Resilience as an entrepreneurial capability: integrating insights from a cross-disciplinary comparison. *Int. J. Entrepreneurial Behav. Res.* 24, 1155–1180. doi: 10.1108/IJEBR-11-2016-0368

March, J. G. (1991). Exploration and exploitation in organizational learning. *Org. Sci.* 2, 71–87. doi: 10.1287/orsc.2.1.71

March, J. G. (2010). *The Ambiguities of Experience.* Ithaca, NY: Cornell University Press.

Martinelli, E., Tagliazucchi, G., and Marchi, G. (2018). The resilient retail entrepreneur: dynamic capabilities for facing natural disasters. *Int. J. Entrepreneurial Behav. Res.* 24, 1222–1243. doi: 10.1108/IJEBR-11-2016-0386

Miles, M. B., and Huberman, A. M. (1994). *Qualitative Data Analysis: An Expanded Sourcebook.* 2nd Edn. Thousand Oaks, CA: Sage.

Morais-Storz, M., and Nguyen, N. (2017). The role of unlearning in metamorphosis and strategic resilience. *Learn. Org.* 24, 93–106. doi: 10.1108/TLO-12-2016-0091

Mousa, M., Abdelgaffar, H. A., Chaouali, W., and Aboramadan, M. (2020). Organizational learning, organizational resilience and the mediating role of multi-stakeholder networks A study of Egyptian academics. *J. Workplace Learn.* 32, 161–181. doi: 10.1108/JWL-05-2019-0057

Mousa, M., Sai, A., and Salhin, G. (2017). An exploration for the motives behind enhancing senior banker's level of organizational resilience: a holistic case study. *J. Intercultural Manage.* 9, 141–163. doi: 10.1515/joim-2017-0025

Naimoli, J. F., and Saxena, S. (2018). Realizing their potential to become learning organizations to foster health system resilience: opportunities and challenges for health ministries in low- and middle-income countries. *Health Policy Plan.* 33, 1083–1095. doi: 10.1093/heapol/czy100

Näswall, K., Kuntz, J., Hodliffe, M., and Malinen, S. (2013). *Employee Resilience Scale (EmpRes): Resilient Organisations Research Report 2013/06 ISSN 1178-7279.* Available online at: http://hdl.handle.net/10092/9469 (accessed December 12, 2021).

Nicolletti, M., Lutti, N., Souza, R., and Pagotto, L. (2019). Social and organizational learning in the adaptation to the process of climate change: the case of a Brazilian thermoplastic resins and petrochemical company. *J. Clean. Prod.* 226, 748–758. doi: 10.1016/j.jclepro.2019.04.058

Nyman, M. R. (2019). collective learning in organizations: opportunities and constraints. Case study of an avalanche blocking a railway line. *Risk Hazards Crisis Public Policy* 10, 332–359. doi: 10.1002/rhc3.12159

Örtenblad, A. (2004). The learning organization: towards an integrated model. *Learn. Org.* 11, 129–144. doi: 10.1108/09696470410521592

Orth, D., and Schuldis, P. M. (2021). Organizational learning and unlearning capabilities for resilience during COVID-19. *Learn. Org.* 28, 509–522. doi: 10.1108/TLO-07-2020-0130

Pal, R., Torstensson, H., and Mattila, H. (2014). Antecedents of organizational resilience in economic crises: an empirical study of Swedish textile and clothing SMEs. *Int. J. Prod. Econ.* 147, 410–428. doi: 10.1016/j.ijpe.2013.02.031

Parsons, D. (2010). Organisational resilience. *Aust. J. Emerg. Manage.* 25, 18–20. doi: 10.3316/ielapa.084557405183732

Patriarca, R., Di Gravio, G., Costantino, F., Falegnami, A., and Bilotta, F. (2018). An analytic framework to assess organizational resilience. *Saf. Health Work* 9, 265–276. doi: 10.1016/j.shaw.2017.10.005

Petrie, D. A., and Swanson, R. C. (2018). The mental demands of leadership in complex adaptive systems. *Healthcare Manage. Forum* 31, 206–213. doi: 10.1177/0840470418778051

Popova-Nowak, I. V., and Cseh, M. (2015). The meaning of organizational learning:a meta-paradigm perspective. *Hum. Resource Dev. Rev.* 14, 299–331. doi: 10.1177/1534484315596856

Powley, E. H., and Cameron, K. S. (2020). "Resilience and organizational culture: a competing values perspective," in *Research Handbook on Organizational Resilience*, editors E. H Powley, B. B. Caza, and A. Caza (Cheltenham, UK: Edward Elgar), 261–274.

Prasad, S., Su, H. C., Altay, N., and Tata, J. (2015). Building disaster-resilient micro enterprises in the developing world. *Disasters* 39, 447–466. doi: 10.1111/disa.12117

Provan, D. J., Woods, D. D., Dekker, S. W. A., and Rae, A. J. (2020). Safety II professionals: how resilience engineering can transform safety practice. *Reliab. Eng. Syst. Saf.* 195, 106740. doi: 10.1016/j.ress.2019.106740

Rangachari, P., and Woods, J. L. (2020). Preserving organizational resilience, patient safety, and staff retention during COVID-19 requires a holistic consideration of the psychological safety of healthcare workers. *Int. J. Environ. Res. Public Health* 17, 4267. doi: 10.3390/ijerph17124267

Reich, B. H. (2007). Managing knowledge and learning in it projects: a conceptual framework and guidelines for practice. *Proj. Manage. J.* 38, 5–17. doi: 10.1177/875697280703800202

Ritz, F., Kleindienst, C., Brüngger, J., and Koch, J. (2015). Coping with unexpected safety-critical situations: a concept for resilient (simulator) team training for control room teams. *Proc. Manufact.* 3, 1865–1871. doi: 10.1016/j.promfg.2015.07.228

Rodríguez-Sánchez, A., Guinot, J., Chiva, R., and López-Cabrales, Á. (2021). How to emerge stronger: antecedents and consequences of organizational resilience. *J. Manage. Org.* 27, 442–459. doi: 10.1017/jmo.2019.5

Rodríguez-Sánchez, A. M., and Vera Perea, M. (2015). The secret of organisation success: a revision on organisational and team resilience. *Int. J. Emerg. Serv.* 4, 27–36. doi: 10.1108/IJES-09-2014-0018

Ruiz-Martin, C., López-Paredes, A., and Wainer, G. (2018). What we know and do not know about organizational resilience. *Int. J. Prod. Manage. Eng.* 6, 11–28. doi: 10.4995/ijpme.2018.7898

Salanova, M. (2020). How to survive COVID-19? Notes from organisational resilience. *Int. J. Soc. Psychol.* 35, 670–676. doi: 10.1080/02134748.2020.1795397

Schilling, J., and Kluge, A. (2009). Barriers to organizational learning: an integration of theory and research. *Int. J. Manag. Rev.* 11: 337–360. doi: 10.1111/j.1468-2370.2008.00242.x

Scholten, K., Scott, P. S., and Fynes, B. (2019). Building routines for non-routine events: supply chain resilience learning mechanisms and their antecedents. *Supply Chain Manage. Int. J.* 24, 430–442. doi: 10.1108/SCM-05-2018-0186

Schöpfel, J. (2010). "Towards a Prague definition of grey literature," in *Twelfth International Conference on Grey Literature: Transparency in Grey Literature. Grey Tech Approaches to High Tech Issues. Prague, 6–7 December 2010*, 11–26.

Sengul, H., Marsan, D., and Gun, T. (2019). Survey assessment of organizational resiliency potential of a group of Seveso organizations in Turkey. *Proc. Inst. Mech. Eng. Part O J. Risk Reliab.* 233, 470–486. doi: 10.1177/1748006X18802655

Sitkin, S. B. (1992). Learning through failure: the strategy of small losses. *Res. Org. Behav.* 14, 231–266.

Starbuck, W. H. (1967). Organizational metamorphosis. *Acad. Manage. Proc.* 1, 113–132. doi: 10.5465/ambpp.1967.4980662

Steen, R., and Ferreira, P. (2020). Resilient flood-risk management at the municipal level through the lens of the functional resonance analysis model. *Reliabil. Eng. Syst. Saf.* 204, 107150. doi: 10.1016/j.ress.2020.107150

Suryaningtyas, D., Sudiro, A., Eka, T. A., and Dodi, I. W. (2019). Organizational resilience and organizational performance: examining the mediating roles of resilient leadership and organizational culture. *Acad. Strat. Manage. J.* 18, 1. Available online at: https://www.abacademies.org/journals/academy-of-strategic-management-journal-home.html (accessed December 12, 2021).

Sutcliffe, K. M., and Vogus, T. J. (2003). "Organizing for resilience," in *Positive Organizational Scholarship: Foundations of a New Discipline*, editors K. S. Cameron, J. E. Dutton, and R. E. Quinn (San Francisco, CA: Berrett-Koehler), 94–110.

Tasic, J., Amir, S., Tan, J., and Khader, M. (2020). A multilevel framework to enhance organizational resilience. *J. Risk Res.* 23, 713–738. doi: 10.1080/13669877.2019.1617340

Taylor, G., Templeton, G., and Baker, L. (2010). Factors influencing the success of organizational learning implementation: a policy facet perspective. *Int. J. Manag. Rev.* 12, 353–364. doi: 10.1111/j.1468-2370.2009.00268.x

Tsang, E. W. K., and Zahra, S. A. (2008). Organizational unlearning. *Hum. Relat.* 61, 1435–1462. doi: 10.1177/0018726708095710

Ungar, M. (2018). Systemic resilience: principles and processes for a science of change in contexts of adversity. *Ecol. Soc.* 23, 17. doi: 10.5751/ES-10385-230434

van Trijp, J., Boersma, K., and Groenewegen, P. (2018). Resilience from the real world towards specific organisational resilience in emergency response organisations. *Int. J. Emerg. Manage.* 14, 303–321. doi: 10.1504/IJEM.2018.097358

Vogus, T. J., and Sutcliffe, K. M. (2007). "Organizational resilience: towards a theory and research agenda," in *IEEE International Conference on Systems, Man and Cybernetics*, 3418–3422.

Walsh, J. P., and Ungson, G. R. (1991). Organizational memory. *Acad. Manage. Rev.* 16, 57–91. doi: 10.2307/258607

Weick, K. E., and Sutcliffe, K. M. (2015). *Managing the Unexpected: Sustained Performance in a Complex World*, 3rd Edn. New Jersey, NY: John Wiley & Sons Inc.

Wright, C., Suh, C. S., and Leggett, C. (2009). If at first you don't succeed: globalized production and organizational learning at the Hyundai Motor Company. *Asia Pacific Bus. Rev.* 15, 163–180. doi: 10.1080/13602380701698418

Xiao, Y., and Watson, M. (2019). Guidance on conducting a systematic literature review. *J. Plan. Educ. Res.* 39, 93–112. doi: 10.1177/0739456X17723971

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Communication

ORIGINAL RESEARCH
published: 02 March 2022
doi: 10.3389/fcomm.2022.822302

Trust: A Double-Edged Sword in Combating the COVID-19 Pandemic?

Jon Reiersen, Kristin Roll, Jesse Dylan Williams and Michael Carlsson*

School of Business, University of South-Eastern Norway, Kongsberg, Norway

We examine the impact of trust in combating the SARS-CoV-2 virus, that can cause COVID-19. Under normal circumstances trust is a crucial component for society to function well, but during a pandemic trust can become a double-edged sword. On the one hand, a high level of trust in society may lead to greater acceptance among citizens for public measures that aim to combat a virus. If people believe that their respective governments implement unbiased and well-informed measures, and people also believe that their fellow citizens will follow these measures, this may lead to a high general compliance in society and less people will be infected. On the other hand, trust may affect people's perception of risk and hence their behavior. If people believe that most people are trustworthy, they may be less willing to think of everyone else as a potential health threat. If people also trust the government to manage the pandemic in a competent way, their perception of the risks related to the pandemic weaken. Taken together, this may lead people in high trust societies to consider personal protective measures less important, and more people will be infected. The ambiguous effect trust may have on the outcome of a pandemic calls for a closer empirical analysis. Drawing on data from 127 countries we find that the number COVID-19 deaths decrease with trust in government and trust in science, while the number COVID-19 deaths increase with social trust. Implications of these findings for risk communication and management during a pandemic are discussed.

Keywords: trust, risk perception, pandemic, public compliance, COVID-19

OPEN ACCESS

Edited by:
Johan Berlin,
University West, Sweden

Reviewed by:
Lars Frelin,
Karolinska Institutet (KI), Sweden
Jörn Boehnke,
University of California, Davis, United States
John James Kiefer,
University of New Orleans, United States

****Correspondence:***
Jon Reiersen
jon.reiersen@usn.no

Specialty section:
This article was submitted to Disaster Communications, a section of the journal Frontiers in Communication

Received: *25 November 2021*
Accepted: *01 February 2022*
Published: *02 March 2022*

Citation:
Reiersen J, Roll K, Williams JD and Carlsson M (2022) Trust: A Double-Edged Sword in Combating the COVID-19 Pandemic? Front. Commun. 7:822302. doi: 10.3389/fcomm.2022.822302

INTRODUCTION

On December 31, 2019, the Wuhan Municipal Health Commission reported a cluster of pneumonia cases in China. The outbreak of the disease was later identified as caused by a new virus, SARS-CoV-2—a virus that can lead to COVID-19. The emergence of the new virus rapidly escalated to a public health emergency of international concern. On March 11, 2020, the World Health Organization declared that the world was faced with a considerable threat, and the COVID-19 outbreak was officially characterized as a pandemic. This in turn led to a variety of measures put in place by governments worldwide to control and contain the spread of the virus. Governments have responded in various manners ranging from recommended hygiene practices and use of face masks through to social distancing and complete lockdowns of society. Despite strong measures, millions have been infected and more than 5 million have died due to COVID-19 (by October 29, 2021).

Human behavior critically affects how a pandemic develops. An essential contribution to the successful management of a pandemic is that most people comply with the health authorities' recommendations. If people adopt good hygienic routines, keep physical distance and get vaccinated (when an effective vaccine becomes available), a pandemic can be brought under control. It seems to be widely believed that trust is a critical factor to achieve this. The argument put forth by commentators and others is that trust increases the likelihood that people follow the authorities' recommendations and carry out personal protective measures. Norway can serve as an example. In a comparative perspective, Norway has had relatively few infections and deaths as a result of COVID-19.[1] An independent Coronavirus Commission report (NOU, 2021, p. 6) assessing the Norwegian authorities' management of the COVID-19 pandemic attributes the high level of social trust in Norway as a strength in combating the virus (but without doing any serious attempt to document this empirically).[2] Prior to the publication of the report, the Prime Minister of Norway had proclaimed in a televised speech (broadcasted March 18, 2020) that the high level of trust in Norway provided the country "… with an advantage throughout the pandemic, more effective than any weapon and more valuable than any oil fund".[3]

An important reason for why trust is generally seen as a critical factor in combating a pandemic is probably the extensive research showing that trust is an important condition for a society to function well (see e.g., Fukuyama, 1995; Yamagishi, 2011; Algan and Cahuc, 2013, among many others). When people trust each other, economic transactions run more smoothly (Torsvik, 2000), collective action problems are more easily solved (Ostrom, 2003), society is more inclusive and open (Fukuyama, 1995; Lazzarini et al., 2008; Yamagishi, 2011), there is less corruption and better governance (Rothstein, 2011), and people generally are happier and have better health (Putnam, 2000; Uslaner, 2002). Based on available evidence it is fairly safe to conclude that under normal circumstances, trust is a valuable asset for a society. A pandemic, however, does not represent "normal circumstances". Recent research has shown that trust is not a panacea that guarantees successful crisis management, including crisis management during a pandemic.

Trust plays an important role in peoples' assessment of risk and thus their behavior (Siegrist and Cvetkovich, 2000; Earle, 2010). Terpstra (2011) studied Dutch citizens' flood preparedness and found that a higher level of trust in flood risk experts reduced both the citizens' perception of the likelihood of flooding and the amount of fear caused by the risk of flooding. Both mechanisms hampered the citizens' flood preparedness. Likewise, Wong and Jensen (2020) show that that trust can be a barrier to the desired behavior from the governments' point of view. They report that the strong trust in the governments' crisis management led the citizens to accept the governments' advice and recommendations to a lesser extent during the COVID-19 pandemic in Singapore. Similar findings are also noted from other countries. Wollebæk et al. (2020) found that Norwegians that strongly believe that most people can be trusted are less worried about the consequences of the COVID-19 pandemic and they are also less willing to comply with the governments' infection control measures. At the same time, they also found that the amount of trust Norwegians have in the government is positively related to compliance with the governments' recommendations. Those who trust the government a lot follow more of the recommendations compared to those who have little trust in the government. That is, social trust and trust in government seem to have opposite effects on the acceptance of measures to reduce COVID-19 cases. Similar results are noted from Switzerland. Siegrist et al. (2021) carried out a survey in March-April 2020, to study how different dimensions of trust influence peoples' risk perception and their acceptance of the implemented measures to control the pandemic. They found that peoples' fear associated with COVID-19 is negatively correlated with social trust, but they also found that peoples' acceptance of the implemented measures to control the pandemic was positively correlated with trust in government. Again, social trust and trust in government seem to have opposite effects.

Drawing on data on social trust and COVID-19 deaths for 37 countries, Arachchi and Managi (2021) found that social trust was associated with more COVID-19 deaths, where they also controlled for several other variables. Elgar et al. (2020) reach the same conclusion when analyzing cross-national differences in COVID-19 deaths for 84 countries during the early phase of the pandemic. However, Helliwell et al. (2021) report the opposite result when analyzing COVID-19 deaths in 163 countries and using income inequality as a proxy for social trust.[4] They found that inequality of income is a strong predictor of a higher COVID-19 death rate. Helliwell et al. (2021) also found that little trust in public institutions is associated with more COVID-19 deaths. Bargain and Aminjonov (2020) look at the impact of trust in policy makers on peoples' compliance to health policy rules. In particular, they examine how trust at regional level in Europe effects mobility related to non-necessary activities around the time of lock-down announcement (March 2020). They find that the decline in mobility is significantly stronger in high-trust regions in Europe.

[1]By October 29, 2021, Norway has 164 COVID-19 deaths per million people. In comparison, the country with most confirmed COVID-19 deaths is Peru, with 6,002 deaths per million people. The US has 2,240 deaths per million while the average for the world is 634 deaths per million people (Ritchie et al., 2021).

[2]Social trust varies widely across countries. Empirical research investigating the relationship between trust and various measures of quality of society usually draws on data from the World Value Survey (WVS), where trust is derived from the dichotomous question: "Generally speaking, would you say that most people can be trusted or that you need to be very careful in dealing with people?" with the response alternatives "Most people can be trusted" and "Need to be very careful." On average, in the world as total, around 25% state that most people can be trusted. On top of the list we find Norway with a score of 74%. In comparison, The United States has a trust score of around 38%, while France and Spain are down at around 18%. Countries showing low levels of trust are Romania (7%), Colombia (4%), and the Philippines (3%) (WVS, Wave Five and Six 2005–2013).

[3]Norway's oil fund was created after Norway discovered oil in the North Sea in the late 1960. The fund is now one of the world's largest funds, with over US 1.3 trillion in assets which is about US 245,000 per Norwegian citizen.

[4]Many studies have noted that social trust is generally lower in countries where income inequality is higher.

Research from previous pandemics also note the importance of trust for people's willingness to comply with the governments' recommendations and for the outcome of a pandemic. Studies from several countries have found that people who trust medical and political authorities, as well as the media, were more likely to adopt the recommended behavior in order to control the 2009–2010 pandemic of swine influenza, caused by the H1N1 virus (Rubin et al., 2009; Gilles et al., 2011; Prati et al., 2011; Freimuth et al., 2014; Chuang et al., 2015). Tang and Wong (2005) report that lack of trust in the government was strongly associated with public anxiety during the 2003 SARS outbreak in Hong Kong, while Blair et al. (2017) found that those who had less trust in the government were less likely to take precautions during the 2014–2016 Ebola outbreak in Liberia and Congo.

Taken together, available evidence provides mixed results when it comes to how trust affects the outcome of a pandemic and it also demonstrates that different dimensions of trust can affect people's assessment of risk, their behavior, and the outcome of a pandemic in very different ways. Analyses of how trust is related to the outcome of a pandemic should therefore distinguish between different types of trust and also be open to the possibility that different types of trust can have different effects on how people perceive risk and react to a pandemic (Poortinga and Pidgeon, 2003; Siegrist and Zingg, 2014; Wong and Jensen, 2020; Siegrist and Bearth, 2021; Siegrist et al., 2021). In this study we examine how trust in fellow citizens, trust in government and trust in science affect the number of confirmed COVID-19 deaths. To investigate this issue, we collected data for 127 countries around the world. Building on previous literature we also include other variables that are likely to affect the outcome of a pandemic. These variables are discussed in more detail in the next section, together with a closer examination of the relationship between trust and human behavior during a pandemic, and the hypotheses we can derive from this examination.

MATERIALS AND METHODS

Social Trust and Cooperation During a Pandemic

As noted, research examining the impact of trust for the outcome of a pandemic have provided mixed results. This is not surprising if we look at what theory can tell us about how trust is likely to affect behavior in a pandemic. Fighting a pandemic has many of the same characteristics as a public goods game. If everyone takes precautions, adopt good hygienic routines, keep physical distance and so on, the pandemic can be brought under control, which is in everyone's best interest. However, if people generally believe that everyone takes their precautions (cooperate), it is tempting to free-ride on the joint efforts of others. In that case, one saves oneself from the cost of taking precautions, at the same time as the pandemic is brought under control as a result of the efforts of others. But of course, if everyone acts as free-riders there will be no public goods—that is, the virus spreads and the society faces a pandemic.

Several experiments with the public goods game show, however, that a large majority are generally willing to contribute and to cooperate, and a minority act as unscrupulous free-riders. Conditional cooperation seems to be the predominant behavioral pattern for contributions in experimental public goods games (Fischbacher et al., 2001; Fehr and Gächter, 2002; Herrmann and Thöni, 2009; Volk et al., 2012). People are generally willing to cooperate in public goods games as long as they trust others to do the same. This points in the direction that high social trust makes it easier to fight a pandemic, since people are willing to take the necessary precautions as long as they trust others to do the same.

On the other hand, this reasoning does not take into account that in a pandemic the individual is also a potential carrier of a virus. As noted by Siegrist et al. (2021), what matters for the individual's action is not only what one thinks about the actions of others, but also what one thinks about the risk of others carrying a virus. If people believe that most people are trustworthy, they may be less willing to think of everyone else as a potential health threat (that they carry a virus), and they will consider personal protective measures less important. More people will be infected, and the pandemic is more difficult to fight.

The Role of Trust in Government and Trust in Science

There are also mechanisms pointing in the direction that trust in government and trust in science has an ambiguous impact on the outcome of a pandemic. When people have to make choices faced with a situation they are unfamiliar with, they usually lack the knowledge they need to make an informed decision. A pandemic typically represents such a situation. Most people do not have sufficient information on how to behave, especially during the initial phase of a pandemic outbreak. People have to rely on information provided by others when making a decision. If people generally trust those who give the government scientific and professional advice, and if people believe that the government implements unbiased and well-informed measures, this can lead to greater acceptance among citizens for the measures put in place by the government to combat a virus.

However, trust in the government and trust in science can have the opposite effect, as showed by Wong and Jensen (2020). High trust in the government and other authorities can lead to an underestimation of the risk of a pandemic and a perception that individual action is not required. People may believe that the government will do the necessary effort to combat the pandemic. High trust in the government and other authorities may in other words crowd out peoples' motivation to carry out individual sacrifices.

To sum up: During a pandemic, different types of trust can affect people's behavior in different ways. It is therefore difficult to determine from the outset whether trust is detrimental or beneficial in fighting a pandemic. We must leave it to our empirical analysis to determine what effect the different dimensions of trust have on the outcome of the COVID-19 pandemic.

Empirical Specification

To investigate how trust affects the outcome of a pandemic, we estimate a multivariable regression model. A multivariable model allows us to incorporate other relevant explanatory variables, expected to affect the outcome of a pandemic. In addition

to the key explanatory variables of trust we include, gross domestic product per capita, population density, median age of the population, numbers of bordering countries, a health index and we control for continent. To assist the interpretation of the results, the estimated model is specified on log-log form, which derives the elasticities directly from the parameters.

The estimated model is given as follows:

$$\begin{aligned}\ln(DPMP_i) &= \beta_0 + \beta_{TGOV}\ln(TRUSTGOV_i)\\ &+\beta_{TSOS}\ln(TRUSTSOS_i) + \beta_{TSCI}\ln(TRUSTSCI_i)\\ &+\beta_{GDP}\ln(GDP_i) + \beta_{POP}\ln(POPDEN_i)\\ &+\beta_{AGE}\ln(MEDAGE_i) + \beta_{BORDC}\ln(BORDC_i)\\ &+\beta_{HI}\ln(HINDEX_i) + \sum_C \beta_C(CONTINENT_C) \qquad (1)\end{aligned}$$

where the dependent variable, $DPMP_i$, is the *total confirmed COVID-19 deaths per million people* for country *i*.[5] The numbers are retrieved from Ritchie et al. (2021), on September 28, 2021.

Our key explanatory variables $TRUSTGOV_i$, $TRUSTSOS_i$, and $TRUSTSCI_i$ are measuring country *i*'s level of *trust in the government*, *trust in society* and *trust in science*. The three variables are derived from the indicator included in the Wellcome Global Monitor 2018 (Wellcome Trust and The Gallup Organization Ltd., 2019). In their yearly global survey, they are asking the following questions:

- Trust in government: How much do you trust the national government in this country.
- Social trust: How much do you trust people in your neighborhood.
- Trust in Science: How much do you trust scientists in this country.

Respondents were provided with the following six answer alternatives: A lot, some, not much, not at all, don't know and neutral. The value that has been assigned to these variables is the share of respondents who answered with the alternatives "A lot" or "Some". Given the ambiguous relationship between the three different dimensions of trust and the number of COVID-19 deaths, as discussed above, we do not have a straightforward hypothesis on the direct relationship between the degree of trust and the outcome of the COVID-19 pandemic.

GDP_i measuring the *gross domestic product per capita* in country *i* and is expressed in constant 2017 international dollars and converted by purchasing power parity. The numbers are taken from the World Bank (2021a). Measures to limit the spread of the coronavirus have major consequences for the economy. Rich countries are more capable of enduring prolonged economic downturn and are therefore also more likely to implement more stringent restrictions to mitigate the transmission of the virus. Hence, we expect fewer COVID-19 deaths in countries with a higher GDP per capita.

$POPDEN_i$ measuring *population density* in country *i*, and is defined as population per sq. km of land area. This variable is also taken from the World Bank (2021b). OECD (2020) emphasize population density as a contributing factor to the effectiveness of containment strategies. Considering that social distancing is a dominant containment measure, it is expected that this will be more effective in countries and communities with lower population density. We therefore expect that countries with a higher population density will experience a higher rate of COVID-19 deaths.

$MEDAGE_i$ measuring the *median age* in country *i*, and indicates the point of age in which half of the population is younger, and half of the population is older. The numbers are retrieved from the United Nations (2021). It is well documented that the likelihood of becoming seriously ill and dying from COVID-19 is increasing with age (OECD, 2020). Medina (2020) shows for example that patients over the age of 60 are 8.15 times more likely to die from COVID-19 than patients under the age of 60. Populations with more elderly people have more individuals at risk of dying from the virus, and we therefore expect that a higher median age will result in a higher rate of COVID-19 deaths.

$BORDC_i$ measuring the *number of countries bordering* country *i*, and is defined as the number of land boundaries each country has on a ratio scale where zero is the lowest value (a value of 0 signifies that a country has no land boundaries[6]). The numbers are taken from World Factbook (2021). Analysis of the Ebola outbreak shows that cross-border exchange of preparedness and response co-ordination is imperative (Olu et al., 2020). The implementation of border control measures in response to the pandemic will probably be more difficult for countries with more bordering countries, and we therefore expect that a higher number of bordering countries will result in a higher number of COVID-19 deaths.

$HINDEX_i$ is a *health index* compromised by 13 indicators including life expectancy, physician rate, mortality rates and free/universal healthcare which are important components of health equity (Hudson International Group, 2021). The index value is a weighted average converted to a score on a ratio scale ranging from 0 to 1 where 0 is the lowest score, and 1 is the highest score. The quality of the health care system is a critical factor when a country is hit by a pandemic.[7] Access to equipment, medicines, the number of doctors and nurses per inhabitant, public funded vs. private provision of health services and a number of other factors contribute to determine the quality of the health care system. Countries with a high level of health equity should be better equipped to treat the population including those most marginalized and vulnerable in the face of a pandemic (OECD, 2020). A Mexican study found, for example, the lack of

[5]An alternative response variable, *contracted cases per million people,* were also considered but deemed unreliable for the analyses due to underreporting of this variable. There is a wide variation in testing practices leading to underreporting of cases that do not necessarily represent the actual situation. A recent study (Rahmandad et al., 2021) has estimated that the ratio of actual to reported cumulative cases is 7.03, corresponding to 465 million undetected cases. The occurrence of asymptomatic infections can also explain a large proportion of underreporting. In comparison, it is estimated that the actual number of deaths is 1.44 times higher than official reports.

[6]To facilitate the logarithmic transformation, we are following Weninger (1998), and modify zero-value arguments by replacing them with arbitrarily small values.

[7]See OECD (2020) for a more thorough analysis and discussion.

TABLE 1 | Summary statistics for the sample variables.

	COVID-19 deaths	Mean	Std. Dev.	Min	Max	Source
Number of deaths per million (DPMP)		1,090	1,015	1	5,975	Ritchie et al., 2021
Trust in the government (*TRUSTGOV*)	±	0.514	0.188	0.110	0.990	Wellcome Global Monitor
Trust in society (*TRUSTSOS*)	±	0.730	0.142	0.310	0.960	Wellcome Global Monitor
Trust in science (*TRUSTSCI*)	±	0.746	0.132	0.400	0.980	Wellcome Global Monitor
Gross domestic product per capita (*GDP*), 2019	−	16,629	21,477	412	114705	World Bank
No of bordering countries (*BORDC*)	+	4.21	2.26	0.00	14.00	The World Factbook
Population density (*POPDEN*)	+	113	126	2	669	World Bank
Median age (*MEDAGE*)	+	31.60	9.10	15.80	47.10	United Nations
Health index (*HINDEX*)	−	0.658	0.253	0.010	0.940	Hudson International Group
Africa		0.234	0.425	0	1	
Asia		0.224	0.419	0	1	
Australia		0.019	0.136	0	1	
North America		0.327	0.471	0	1	
South America		0.103	0.305	0	1	

health services to the indigenous population put them at a higher risk of vulnerability in the presence of the COVID-19 pandemic (Díaz de León-Martínez et al., 2020). We therefore expect that a higher health index value will result in fewer COVID-19 deaths.

Finally, *CONTINENT* is a dummy variable included to control for continent-specific effects. The countries have been categorized into one of the following continents: Asia, Africa, North America, South America, Australia or Europe. In our estimated model the default category consists of countries in Europe.

Table 1 summarizes the basic hypotheses and structure that guide our analysis together with some descriptive statistics. Because of the ambiguous relationship between the different dimensions of trust and the number of COVID-19 deaths, these variables are marked with ± in column two. The other variables included in our analysis have a more unambiguous expected effect on the number of COVID-19 deaths, and this is marked with either + (the variable is expected to have an increasing effect on the number of COVID-19 deaths) or—(the variable is expected to have a decreasing effect on the number of COVID-19 deaths) in column two in **Table 1**.

As **Table 1** illustrates, the dataset used in the study is built from several sources. Our sample started out with 127 observations/countries, but due to missing observations in several of the explanatory variables (among others the trust variables), our sample reduces to 107 observations. Stata 15 software was used for all analyses.

RESULTS

Before estimation, a classical additive disturbance term was appended to Equation (1). The empirical model was first estimated using OLS. A Breusch-Pagan test for the null hypotheses of homoskedasticity was however rejected at a 0.001 level of significance, indicating problems with heteroskedasticity in the data.[8] To ensure that the assumption of *constant variance* is fulfilled, the model was reestimated with robust standard errors.[9]

TABLE 2 | COVID-19 deaths per million people: Regression results.

	Coef.	Robust std. Err.	*t*-value	*p*-value
Trust in government (*TRUSTGOV*)	−0.553	0.247	−2.240	0.028
Trust in society (*TRUSTSOS*)	2.072	0.819	2.530	0.013
Trust in science (*TRUSTSCI*)	−3.580	1.427	−2.510	0.014
Gross domestic product per capita (*GDP*)	0.299	0.152	1.970	0.052
No of bordering countries (*BORDC*)	0.352	0.203	1.730	0.087
Population density (*POPDEN*)	−0.056	0.097	−0.580	0.565
Median age (*MEDAGE*)	2.003	0.946	2.120	0.037
Health index (*HINDEX*)	0.430	0.322	1.340	0.185
Africa	−0.707	0.676	−1.050	0.298
Asia	0.023	0.470	0.050	0.962
Australia	−1.382	1.684	−0.820	0.414
North America	0.440	0.404	1.090	0.279
South America	0.915	0.451	2.030	0.045
Constant	−3.988	4.256	−0.940	0.351

The estimated parameters are reported in **Table 2**. Most of the slope parameters are statistically significant at the 0.05 level. The R^2-value for the estimated model is 67.56 and indicates that the data fits the model well.

[8]The chi^2-value of the test is found to be 29.05.

[9]We also conducted a statistical test to check for normality-distributed errors, which showed that this assumption is met.

The main focus of this paper is the effect of different dimensions of trust in combating the COVID-19 pandemic. The first three lines of **Table 2** report to what degree *trust in government*, *trust in society* and *trust in science* effect a countries' deaths caused by COVID-19. All three trust variables are found to be significant at a 5% level, indicating that the three dimensions of trust included in the analysis are important.

Trust in science is found to be most important trust variable with an estimated parameter of −3.6, indicating that a 1% increase in this type of trust level will decrease COVID-19 related deaths by 3.6%. We believe that vaccination is part of the explanation for this result. When we collected data for the number of COVID-19 deaths (September 28, 2021), vaccines were available in many countries, particularly in the rich industrialized part of the world. We know from studies of previous pandemics, such as the SARS epidemic and the 2009/10 H1N1 influenza, that trust in medical experts and organizations had a positive impact on vaccination behavior. In countries with little trust, vaccine uptake remained low (see Siegrist and Zingg, 2014, for a review of studies). This is not surprising. There is reason to believe that the public initially has limited knowledge and information about a new vaccine—how safe they are, if they have been adequately tested, how effective they are and so on. People must therefore rely on the information provided when deciding whether to be vaccinated. Trust becomes important regarding whom to believe. Information from the scientific community is therefore mediated by trust, and trust becomes crucial for the publics' reception and acceptance (Siegrist and Zingg, 2014; Warren and Lofstedt, 2021). If the scientific community recommend vaccination, and people generally believe that those who make up the scientific community are competent and objective, more people will get vaccinated, and the death rates go down. In the same way, trust will also be important for the public's acceptance of other preventive measures that the scientific community recommends in order to gain control of a pandemic.

Trust in government is also found to be positive and significant, however the estimated parameter is less than the parameter for trust in science. A 1% increase in the trust in government level decreases the COVID-19 death rate by 0.6%. Many of the advice and measures that health experts and other scientists have proposed through the COVID-19 pandemic have been communicated to the public through different governmental agencies. The results from our analysis supports the idea that the extent to which the public has followed the governments' advice and taken the necessary precautions depends on their trust in the government. This finding is in line with the findings in Bargain and Aminjonov (2020), Arachchi and Managi (2021) and Helliwell et al. (2021). We thus find little support for our alternative hypothesis that high trust in the government crowds out people's willingness to carry out personal sacrifices, and that they leave it to the government to do what it takes to bring the pandemic under control.

Compared to trust in science and trust in government, trust in society is found to have opposite effect on the number of COVID-19 deaths. A 1% increase in the level of social trust worsen the consequences of the COVID-19 pandemic, increasing the death rate by 2.1%. This lends support to the findings referred to above, illuminating that social trust may act as a barrier to behavior that is necessary to reduce the spread of a virus. In countries with high social trust, people generally believe that most people are trustworthy, that they take their precautions and that they stay home if they are sick. Hence, people in high trust societies may be reluctant to think of others as a potential health threat and they may consider personal protective measures less important.

In contrast to our expectation, *GDP per capita* is found to have a negative effect on the number of COVID-19 deaths. The result is almost significant at 5% with a p-value of 0.052. We believe that our findings could be related to the fact that the pandemic is still ongoing and that countries are at different stages of the pandemic. Except from China, high-income countries western-Europe were hit first by the virus. At the time of writing (October, 2021) the COVID-19 pandemic is still ongoing with full force in many poor countries, especially in Africa and parts of Asia.

Number of bordering counties are found to have a positive effect on the number of COVID-19 deaths at a 10% level of significance. This was supported by previous research (Olu et al., 2020; Helliwell et al., 2021), which shows that the implementation of border control measures is more difficult for countries with a high number of bordering countries.

Age is also found to have a strong positive effect on the number COVID-19 deaths. A 1% increase in the median age will increase COVID-19 related deaths by 2%. This is in line with findings in Medina (2020), OECD (2020), and Arachchi and Managi (2021). The virus has disproportionately hit older people and higher death rates from COVID-19 among older people are reported from all over the world.

Our results indicate that there is some continent specific effect. Keeping everything else equal, there is no significant difference in the COVID-19 death rate in Europe, North America, Australia, Asia, or Africa. South America is however found to have a continent-specific effect with a significantly higher death rate. This is most likely explained by the particular high death rates in Peru, Brazil, Argentina and Colombia. At the time of writing, these four South American countries are among the 15 countries in the world with the highest number of COVID-19 deaths per million people.

The variables population density and health index are not found to have a significant effect at any satisfactory level of significance on the number of deaths caused by COVID-19.

DISCUSSION

The COVID-19 pandemic has posed a serious threat to the world community. At the time of writing, over five million have died, millions of people have been infected and nations, firms and individuals have been subjected to great strain (IMF, 2021; WHR, 2021). It is an overriding goal for the authorities to bring the pandemic under control. Strong measures have been implemented by governments in most countries. How a pandemic develops, however, depends critically on how people behave and whether they are willing to follow the authorities' measures and recommendations. It is widely believed that trust is

a key factor in gaining public acceptance of government measures (Siegrist and Zingg, 2014). In societies with little trust, it is difficult to mobilize the necessary collective efforts to gain control of a pandemic. However, our analysis shows that trust is not a panacea for good pandemic management. Trust has many dimensions, and previous studies show that some forms of trust can be a barrier to good pandemic management (Wong and Jensen, 2020; Arachchi and Managi, 2021; Siegrist et al., 2021). Our results support these findings.

The Role of Trust

Trust and risk are closely linked, and social trust has been found to be negatively correlated with risk perception across a broad range of situations (Siegrist and Zingg, 2014). During a pandemic, high social trust may lead to less risk-reducing measures. When people trust each other, they are probably less willing to consider others as a potential health threat, and they will show less precautionary behavior (i.e., keep physical distance). This may be the reason why we find that social trust is negatively associated with the number of COVID-19 deaths.[10]

There are also studies that show that trust in government and trust in science is negatively correlated with risk perception and that this type of trust crowds out peoples' willingness to implement precautionary measures (Wong and Jensen, 2020). Our results do not support this. We find that trust in government and trust science is associated with fewer COVID-19 deaths. Our results therefore suggest that social trust and trust in government and science have opposite effects.

Our analysis also revealed that COVID-19 deaths increased with number of bordering countries, median age and GDP per capita. The last effect probably catches up the fact that rich industrialized countries were hit first by the COVID-19 pandemic and other regions are still in the midst of the pandemic. In addition, South America is found to have a significantly higher death rate compared to the rest of the world.

Trust, Risk Governance, and Communication

The early phase of a pandemic typically represents a situation where people have to make decisions without having a full knowledge of the consequences of the choices they make. Since there is a clear connection between risk perception and behavior, it is important for health experts and government agencies to provide updated information about possible hazards and risks, and thus enable the public to make informed decisions.

As Warren and Lofstedt (2021) emphasize, peoples' risk perceptions are shaped by government communication strategies. Understanding what affects people's risk perception is therefore critical when the government formulate their communication strategy. However, this knowledge is of little value if people are still not willing to listen to the government. If people do not trust the government, it is difficult for them to reach out and correct potential distortions in people's risk perception. As a consequence, people may take wrong preventive actions or that they refuse to follow the recommended behavior. Our study shows that countries where people have little trust in government and little trust in science have more COVID-19 deaths.

The implication of this is as easy as it is difficult. It is important to establish trust in health experts before an outbreak of a pandemic. When a health crisis emerges, the public will have an urgent need for information on how to act. Who they turn to for information depends on who they trust. This means that it is too late for the government and health experts to try to build trust after a pandemic has begun to develop. When the crisis hits, people need to be convinced of who really are the experts among many proclaimed "experts". As Siegrist et al. (2021) notes: "Building the basis for social trust already begins before a pandemic. Ill-prepared government agencies may not be in a good position to be trusted by the public" (p. 798).

Concerning social trust, that is, how many people believe that most people are trustworthy, the general belief seems to be that this form of trust is also unambiguously good for fighting a pandemic. However, our results suggest that social trust is associated with more deaths as a result of COVID-19. We cannot say with certainty what explains this, but a possible interpretation is that when people generally believe that most people are trustworthy, they may be less willing to think of everyone else as a potential health threat and they will consider personal protective measures less important. More people will be infected, and the pandemic is more difficult to fight.

Nevertheless, we cannot conclude from this that social trust makes it difficult to combat a pandemic. As noted above, fighting a pandemic has many of the same features as a public goods game. If everyone takes precautions, adopt good hygienic routines, keep physical distance and so on, the pandemic can be brought under control, which is in everyone's best interest. But, if people generally believe that everyone takes their precautions (cooperate), it is tempting to free-ride on the joint efforts of others. Fortunately, we know from experiments that people are generally willing to cooperate in public goods games as long as they *trust* others to do the same (e.g., Fischbacher et al., 2001; Fehr and Gächter, 2002; Herrmann and Thöni, 2009; Volk et al., 2012). This is how social trust can help in fighting a pandemic. People are more likely to accept pandemic-related restrictions and take the necessary precautions when they have a belief that most others will do the same. It is therefore important that the government, in their communication with the public, build further upon this belief. As Warren and Lofstedt (2020: p. 7) notes: "Promoting social solidarity and collectivism is significant when requiring or requesting that groups undertake altruistic actions or accepts limitations to freedom (...)." The government can contribute to this by referring to examples and stories that illustrate that most people accept and follow up on the measures that have been decided. Too much focus on those who do not comply with the measures can be counterproductive since it easily crowds out people's motivation to make personal sacrifices for the greater benefit of society. Avoiding a "us vs. them" mindset is important for building social trust and creating the necessary

[10]Our analysis covers roughly the first 18 months of the pandemic. As one reviewer suggests, the effect of social trust may change over the course of the pandemic. Even though people trust each other a lot, they may gradually learn that also trustworthy individuals represent a potential health threat during a pandemic. Hence, over time people will show more precautionary behavior also in high trust societies.

collective effort needed to combat a pandemic (Warren and Lofstedt, 2021).

At the same time as the government must strive to maintain and build social trust, it is also critical that they manage to make the citizens aware that those they trust can be a potential health risk, i.e., that they can be carriers of a virus. The authorities must therefore try to communicate a kind of two-part message: Do what it takes to fight the pandemic and trust that most others will do the same—but do not trust that most others are virus free during a pandemic.

The Impact of the Pandemic on Trust

As discussed in this article, many factors contribute to influencing the outcome of the COVID-19 crisis. Along with the vaccine, trust is a key factor. At the same time, there is reason to believe that the pandemic has contributed in shaping trust. Although previous research has shown that trust is a fairly stable variable, there are also studies indicating that trust can be both strengthened and weakened during major crises (Devine et al., 2021; Thoresen et al., 2021).

The COVID-19 pandemic is a massive crisis that has shaken the world and inflicted great social and economic costs on both society and individuals. While an increased sense of "togetherness" and "rally-round-the-flag" mentality is often seen in times of major crisis, it is unclear whether this is the case in the current crisis (Devine et al., 2021). The outbreak and rapid spread of COVID-19 may have undermined peoples' trust in experts and politicians involved in the response effort. Most countries have not been able to control the pandemic, many people have not received the necessary health care, and many have lost their jobs and income. A growing number of countries have also experienced widespread social protests against the government, sometimes followed by counter-protests. This has contributed to reinforcing the political polarization and reduction in social trust that many countries experienced even before the pandemic.

We still need to acquire more knowledge about how different dimensions of trust affect risk perception and behavior during pandemics and crises. The purpose of this article is to contribute to this. To be prepared for the next crisis, we also need to know more about how the COVID-19 pandemic has affected trust in society, and how we can rebuild trust where it has eroded. We believe that this question will be researched intensively in the years to come.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary materials, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

JR conceptualized the research paper, contributed to manuscript writing, data gathering, and interpretation of results. KR contributed to manuscript writing, data analysis, and interpretation. JW and MC contributed to data gathering and critical editing. All authors contributed to the article and approved the submitted version.

REFERENCES

Algan, Y., and Cahuc, P. (2013). "Trust, growth and well-being: new evidence and policy implications," in *Handbook of Economic Growth, Vol. 2A*, eds P. Aghion and S. Durlauf (Amsterdam: Elsevier).

Arachchi, J. I., and Managi, S. (2021). The role of social capital in COVID-19 deaths. *BMC Public Health* 21, 434. doi: 10.1186/s12889-021-10475-8

Bargain, O., and Aminjonov, U. (2020). Trust and compliance to public health policies in times of COVID-19. *J. Public Econ.* 192, 104316. doi: 10.1016/j.jpubeco.2020.104316

Blair, R. A., Morse, B. S., and Tsai, L. L. (2017). Public health and public trust: survey evidence from the Ebola Virus Disease epidemic in Liberia. *Soc. Sci. Med.* 27, 89–97. doi: 10.1016/j.socscimed.2016.11.016

Chuang, Y. C., Huang, Y. L., Tseng, K. C., Yen, C. H., and Yang, L. H. (2015). Social capital and health-protective behavior intentions in an influenza pandemic. *PLoS ONE* 10, e0122970. doi: 10.1371/journal.pone.0122970

Devine, D., Gaskell, J., Jennings, W., and Stoker, G. (2021). Trust and the coronavirus pandemic: what are the consequences of and for trust? An early review of the literature. *Polit. Stud. Rev.* 19, 274–285. doi: 10.1177/1478929920948684

Díaz de León-Martínez, L., de la Sierra-de la Vega, L., Palacios-Ramírez, A., Rodriguez-Aguilar, M., and Flores-Ramírez, R. (2020). Critical review of social, environmental and health risk factors in the Mexican indigenous population and their capacity to respond to the COVID-19. *Scie. Total Environ.* 733, 139357. doi: 10.1016/j.scitotenv.2020.139357

Earle, T.C. (2010). Trust in risk management: A model-based review of empirical research. *Risk Anal.* 30, 541–74. doi: 10.1111/j.1539-6924.2010.01398.x

Elgar, F. J., Stefaniak, A., and Wohl, M. J. A. (2020). The trouble with trust: Time-series analysis of social capital, income inequality, and COVID-19 deaths in 84 countries. *Soc. Sci. Med.* 123, 113365. doi: 10.1016/j.socscimed.2020.113365

Fehr, E., and Gächter, S. (2002). Altruistic punishment in humans. *Nature* 415, 137–140. doi: 10.1038/415137a

Fischbacher, U., Gächter, S., and Fehr, E. (2001). Are people conditionally cooperative? Evidence from a public goods experiment. *Econ. Lette.* 71, 397–404. doi: 10.1016/S0165-1765(01)00394-9

Freimuth, V. S., Musa, D., Hilyard, K., Quinn, S. C., and Kim, K. (2014). Trust during the early stages of the 2009 H1N1 pandemic. *J. Health Commun.* 19, 321–339. doi: 10.1080/10810730.2013.811323

Fukuyama, F. (1995). *Trust. The Social Virtues and the Creation of Prosperity*. New York, NY: The Free Press.

Gilles, I., Bangerter, A., Clemence, A., Green, E. G. T., Krings, F., Staerkle, C., et al. (2011). Trust in medical organizations predicts pandemic (H1N1) 2009 vaccination behavior and perceived efficacy of protection measures in the Swiss public. *Eur. J. Epidemiol.* 26, 203–210. doi: 10.1007/s10654-011-9577-2

Helliwell, J. F., Huang, H., Wang, S., and Norton, M. (2021). "World happiness, trust and deaths under COVID-19," in *Chapter 2 in Helliwell*, eds J. F. Layard, R. Sachs, J. Jan-Emmanuel De Neve. *World Happiness Report 2021* (New York, NY: Sustainable Development Solutions Network).

Herrmann, B., and Thöni, C. (2009). Measuring conditional cooperation: a replication study in Russia. *Exp. Econ.* 12, 87–92. doi: 10.1007/s10683-008-9197-1

Hudson International Group (2021). *The 2021 STC Health Index*. Available online at: https://globalresidenceindex.com/hnwi-index/health-index/ (accessed August 12, 2021).

IMF (2021). *World Economic Outlook. Recovery During a Pandemic: Health Concerns, Supply Disruptions, and Price Pressures*. Washington, DC: International Monetary Fund.

Lazzarini, S. G., Miller, G. J., and Zenger, T. R. (2008). Dealing with the paradox of embeddedness: The role of contracts and trust in facilitating movement out of committed relationships. *Organ. Sci.* 19, 709–728. doi: 10.1287/orsc.1070.0336

Medina, M. A. (2020). *Age As a Risk Factor of COVID-19 Mortality in the Philippines*. Available online at: https://ssrn.com/abstract=3579145

NOU (2021). *Myndighetenes håndtering av koronapandemien — Rapport fra Koronakommisjonen*. Norges Offentlige utredninger nr. 6. Oslo: Departementenes servicesentral.

OECD (2020). *Health at a Glance*. Paris: OECD.

Olu, O. O., Lako, R., Wamala, J. F., Ramadan, P. O., Ryan, C., Udenwese, I., et al. (2020). What did we learn from preparing for cross-border transmission of Ebola virus disease into a complex humanitarian setting – the Republic of South Sudan? *Infect. Dis. Poverty*. 9, 40. doi: 10.1186/s40249-020-00657-8

Ostrom, E. (2003). "Toward a behavioral theory linking trust, reciprocity, and reputation," in *Trust and Reciprocity: Interdisciplinary Lessons from Experimental Research*, eds E. Ostrom and J. Walker (New York, NY: Russel Sage Foundation).

Poortinga, W., and Pidgeon, N. F. (2003). Exploring the dimensionality of trust in risk regulation. *Risk Anal.* 23, 961–972. doi: 10.1111/1539-6924.00373

Prati, G., Pietrantoni, L., and Zani, B. (2011). Compliance with recommendations for pandemic influenza H1N1 2009: the role of trust and personal beliefs. *Health Educ. Res.* 26, 761–769. doi: 10.1093/her/cyr035

Putnam, R. (2000). *Bowling Alone: The Collapse and Revival of American Community*. New York, NY: Simon and Schuster.

Rahmandad, H., Lim, T. Y., and Sterman, J. (2021). Behavioral dynamics of COVID-19: estimating under-reporting, multiple waves, and adherence fatigue across 92 nations. *Syst. Dynam. Rev.* 37, 5–31. doi: 10.1002/sdr.1673

Ritchie, H., Mathieu, E., Rodés-Guirao, L., Appel, C., Giattino, C., Ortiz-Ospina, E., et al. (2021). *Cumulative Confirmed COVID-19 Deaths Per Million People*. Available online at OurWorldInData.org. https://ourworldindata.org/coronavirus (accessed September 28, 2021).

Rothstein, B. (2011). *The Quality of Government: Corruption, Social Trust and Inequality in International Perspective*. Chicago: Chicago University Press.

Rubin, G. J., Amlôt, R., Page, L., and Wessely, S. (2009). Public perceptions, anxiety, and behaviour change in relation to the swine flu outbreak: cross sectional telephone survey. *BMJ*. 339, b2651. doi: 10.1136/bmj.b2651

Siegrist, M., and Bearth, A. (2021). Worldviews, trust, and risk perceptions shape public acceptance of COVID-19 public health measures. *Proc. Natl. Acad Sci. USA*. 118, 1–6 doi: 10.1073/pnas.2100411118

Siegrist, M., and Cvetkovich, G. (2000). Perception of hazards: the role of social trust and knowledge. *Risk Anal.* 20, 713–720. doi: 10.1111/0272-4332.205064

Siegrist, M., Luchsinger, L., and Bearth, A. (2021). The impact of trust and risk perception on the acceptance of measures to reduce COVID-19 cases. *Risk Anal.* 41, 787–800. doi: 10.1111/risa.13675

Siegrist, M., and Zingg, A. (2014). The role of public trust during pandemics: implications for crisis communication. *Eur. Psychol.* 19, 23–32. doi: 10.1027/1016-9040/a000169

Tang, C. S. -K., and Wong, C. -Y. (2005). Psychosocial factors influencing the practice of preventive behaviors against the severe acute respiratory syndrome among older chinese in Hong Kong. *J. Aging Health.* 17, 490–506. doi: 10.1177/0898264305277966

Terpstra, T. (2011). Emotions, trust, and perceived risk: affective and cognitive routes to flood preparedness behavior. *Risk Anal.* 31, 1658–1675. doi: 10.1111/j.1539-6924.2011.01616.x

Thoresen, S., Blix, I., Wentzel-Larsen, T., and Birkeland, M. S. (2021). Trusting others during a pandemic: investigating potential changes in generalized trust and its relationship with pandemic-related experiences and worry. *Front. Psychol.* 12, 698519. doi: 10.3389/fpsyg.2021.698519

Torsvik, G. (2000). Social capital and economic development: a plea for the mechanisms. *Rational. Soc.* 12, 451–476. doi: 10.1177/104346300012004005

United Nations (2021). *World Population Prospects 2019*. Department of Economic and Social Affairs. Population Dynamics. Available online at: https://population.un.org/wpp/DataQuery/ (accessed March 14, 2021).

Uslaner, E. M. (2002). *The Moral Foundation of Trust*. Cambridge: Cambridge University Press.

Volk, S., Thöni, C., and Ruigrok, W. (2012). Temporal stability and psychological foundations of cooperation preferences. *J. Behav. Or.* 81, 664–676. doi: 10.1016/j.jebo.2011.10.006

Warren, G. W., and Lofstedt, R. (2021). Risk communication and COVID-19 in Europe: lessons for future public health crises. *J. Risk Res.* 24, 3–4. doi: 10.1080/13669877.2021.1947874

Wellcome Trust and The Gallup Organization Ltd. (2019). *Wellcome Global Monitor, 2018. [data collection]. 2nd Edition*. UK Data Service. SN: 8466. Available online at: https://beta.ukdataservice.ac.uk/datacatalogue/studies/study?id=8466#!/details (accessed March 14, 2021).

Weninger, Q. (1998). *A General Approach for Estimating the Translog Function in the Presence of Zero-Value Arguments: ISU General Staff Papers 19981212080000133*. Department of Economics, Iowa State University, United States.

WHR (2021). *World Happiness Report 2021*. New York, NY: Sustainable Development Solutions Network.

Wollebæk, D., Enjolras, B., Fladmoe, A., and Steen-Johnsen, K. (2020). *Tillit og bekymring: Hva avgjør om folk følger koronarådene?* Available online at: https://www.samfunnsforskning.no/sivilsamfunn/publikasjoner/hovedfunn/korona-tillit-og-bekymring/tillit-og-bekymring-hva-avgjor-om-folk-folger-koronaradene.pdf (accessed September 28, 2021).

Wong, C. M. L., and Jensen, O. (2020). The paradox of trust: perceived risk and public compliance during the COVID-19 pandemic in Singapore. *J. Res.* 23, 1021–1030. doi: 10.1080/13669877.2020.1756386

World Bank (2021a). *World Development Indicators Database*. Available online at: https://data.worldbank.org/indicator/NY.GDP.PCAP.PP.KD (accessed March 14, 2021).

World Bank (2021b). *Population Density (People per sq. km of Land Area)*. Available online at: https://data.worldbank.org/indicator/EN.POP.DNST (accessed March 14, 2021).

World Factbook (2021). *Land Borders*. Available online at: https://web.archive.org/web/20160408145646/https://www.cia.gov/library/publications/ (accessed March 14, 2021).

Yamagishi, T. (2011). *Trust. The Evolutionary Game of Mind and Society*. London: Springer.

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Public Health

ORIGINAL RESEARCH
published: 09 March 2022
doi: 10.3389/fpubh.2022.755201

Knowledge Mapping Analysis of Public Health Emergency Management Research Based on Web of Science

Li Yang, Xin Fang and Junqi Zhu*

School of Economics and Management, Anhui University of Science and Technology, Huainan, China

At present, major public health emergencies frequently occur worldwide, and it is of great significance to analyze the research status and latest developments in this field to improve the ability of public health emergency management in various countries. This paper took 5,143 related studies from 2007 to 2020 from the Web of Science as research object and used CiteSpace, VOSviewer, and other software to perform co-word analysis, social network analysis, and cluster analysis. The results and conclusions were as follows: (1) the related research identified three periods: the exploration, growth, and outbreak period; (2) chronologically: the relevant research evolved from medical and health care for major diseases to emergency management and risk assessment of public health emergencies and then researched the novel coronavirus (COVID-19) pneumonia epidemic; (3) clustering analysis of high-frequency keywords, identifying three research hotspots: "disaster prevention and emergency medical services," "outbreak and management of infectious diseases in Africa," and "emergency management under the COVID-19 pneumonia epidemic." Finally, this study combined the data and literature analysis to point out possible future research directions: from the research of the COVID-19 pneumonia epidemic to the research of general major public health emergencies, thinking and remodeling of the national public health emergency management system, and exploring the establishment of an efficient international emergency management cooperation mechanism.

Keywords: public health, emergency management, bibliometric analysis, CiteSpace, VOSviewer

OPEN ACCESS

Edited by:
Eric Carlström,
University of Gothenburg, Sweden

Reviewed by:
Krzysztof Goniewicz,
Military University of Aviation, Poland
Feiyu Chen,
China University of Mining and Technology, China

****Correspondence:***
Xin Fang
f470930@163.com

Specialty section:
This article was submitted to Disaster and Emergency Medicine, a section of the journal Frontiers in Public Health

Received: *08 August 2021*
Accepted: *31 January 2022*
Published: *09 March 2022*

Citation:
Yang L, Fang X and Zhu J (2022) Knowledge Mapping Analysis of Public Health Emergency Management Research Based on Web of Science. Front. Public Health 10:755201. doi: 10.3389/fpubh.2022.755201

INTRODUCTION

Public health is the science and technology that prevents diseases, prolongs life, and promotes health through organized efforts and informed choices to benefit public and private institutions, large and small communities, and all individuals in society (1). Since the twenty first century, with the advancement of globalization, the frequency and complexity of public health emergencies have been increasing (2), from SARS, H1N1 influenza, dengue fever to Ebola, MERS, the Zika epidemic (ZIKV), and the recent COVID-19 epidemic, which continues to affect the world. It poses a serious threat to the security of countries worldwide and has had a tremendous impact on people's well-being and social stability. According to the United Nations Political Declaration on Universal Health Coverage

adopted at the relevant high-level meeting of the United Nations General Assembly in 2019, global health is placed at the core of development. Public health issues are related to the sustainable development of the world (3). Emergency management does not only refer to the management of response activities such as preventive preparedness, monitoring, and early warning, disposal and rescue, recovery, and reconstruction before, during, and later stages of an emergency, and the whole life cycle of an emergency (4), but also to the system's ability to respond quickly to emergencies and perform tasks on time (5). Shoaf et al. emphasized the role of public health in disaster risk reduction (6). Singleton et al. systematically discussed the synergy between emergency management and public health, the COVID-19 epidemic that emerged at the end of 2019 and spread worldwide (7). Various secondary and derivative problems caused by it have also become a major global public health emergency caused by compound disaster risk, which has brought tremendous impact and challenges to the construction of emergency management systems and capacity improvement of governments (8–10).

In recent years, research on public health emergency management has rapidly developed. However, there is a lack of literature reviews in this field at home and abroad. Therefore, this paper conducts a scientific and quantitative analysis of the relevant literature on "public health emergency management," referencing relevant scholars to grasp the development context and frontier in the field systematically. Given this study used CiteSpace, VOSviewer, Ucinet, and other software to visually excavate the relevant literature on the theme of "public health emergency management" in the core database of the Web of Science, comprehensively and systematically combed the research status of public health emergency management from 2007 to 2020, and excavated the development trend and hotspot information in this field.

DATA SOURCES AND RESEARCH METHODS

Data Sources

In this study, the core collection database of the Web of Science was selected as the literature source for data retrieval to ensure the data's reliability and authority. English search formula: TS = ("emergency management" or "continuity management" or "crisis management" or "emergency administrator" or "response management" or "disruption management") and ("public health" or "public hygiene"); Index = SSCI, SCI; Time span = 2007–2020; Language: English; Document type: article or review; Database update date: December 26, 2020; Retrieval time: December 26, 2020, a total of 5,173 English literatures were obtained, and 5,143 valid literatures were obtained by using WOS literature output function and CiteSpace de-duplication function.

Research Methods

CiteSpace is a visual network analysis software based on citation analysis theory and Java environment, which is gradually developed under the background of scientometrics, data, and information visualization (11, 12), showing the complex relationship implied in the citation. VOSviewer is a bibliometric analysis software based on the principle of co-citation, which is used to draw a map of scientific knowledge in various knowledge fields (13). The data collected were analyzed visually using the WOS data analysis module in CiteSpace5.5.R2. They obtained relevant information such as the number of articles published year by year, the issuing institutions, the source countries, and the core authors, to evaluate the research status of public health emergency management objectively. Then, VOSviewer was used to generate knowledge maps and related data such as "keyword co-occurrence network" and "author co-citation network" and to analyze the research hotspots and evolution context in this field. Finally, the results of the bibliometric analysis are summarized, and future research directions are discussed.

VISUAL ANALYSIS OF KNOWLEDGE MAP

Analysis of Time Characteristics of Posting Volume

The number of articles published on a specific topic in international academic journals represents the degree of concern of the research topic to a certain extent, and the data of annual publication volume and its growth rate can reflect the rise time of the research topic and the change in its degree of concern. **Figure 1** shows that the earliest article was published in 2007. During the 3 years from 2007 to 2009, the number of papers issued increased year by year, with an average development rate of 113.15%, but the annual number of papers published was at a low level as a whole, which we defined as the initial exploration period of public health emergency management research. The number of papers published in 2010 was 236, with a growth rate of 39.64%, a peak in the curve of the number of papers published and regarded as a mutation value. During 2010–2016, the annual number of papers began to exceed 200, with an average development rate of 110.18%, and the cumulative number of studies was relatively high, which was defined as the continuous development period of the research. From 2017–2020, the average development speed of the number of papers published was 134.17%, showing a rapid explosive trend as a whole, and the number of published papers in 2020 was as high as 1,058, which was defined as the outbreak period. Affected by the COVID-19 pneumonia, public health emergency management research has been increasing annually, and the research fever has been continuously enhanced.

Analysis of Published Journals

Understanding the journal distribution of citation literature can help researchers grasp research hotspots and frontiers in this field through appropriate journals. The distribution of journals with 35 or more papers in the WOS core collection is shown in **Table 1**. The top three journals with the highest number of papers were DISASTER MEDICINE AND PUBLIC HEALTH PREPAREDNESS (146 papers), PLOS ONE (125 papers), and BMC PUBLIC HEALTH (108 papers), accounting for 2.839%, 2.430%, and 2.100% of the sample, respectively. According to the overall distribution of published journals, there are seven journals with more than 40 papers, and these journals published 709 papers, accounting for 13.79% of the total. There

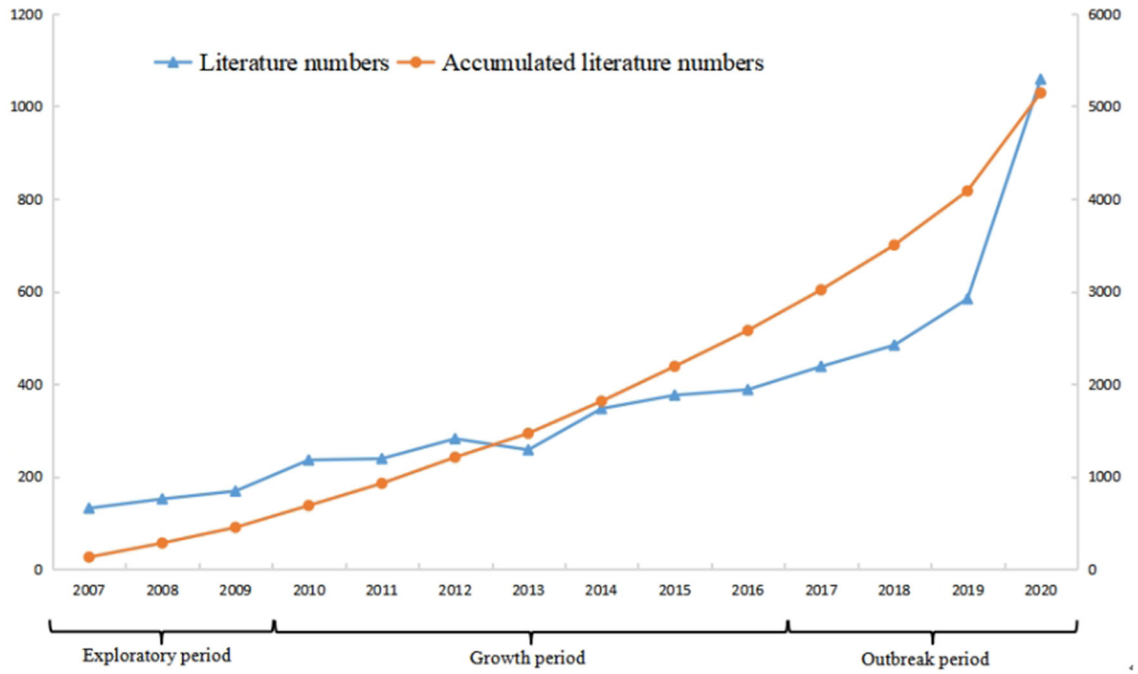


FIGURE 1 | Annual publication of public health emergency management research.

TABLE 1 | Distribution of literature source journals (top 10).

Rank	Journal	*N*	*P* (%)	IF
1	DISASTER MEDICINE AND PUBLIC HEALTH PREPAREDNESS	146	2.839	0.977
2	PLOS ONE	125	2.430	2.740
3	BMC PUBLIC HEALTH	108	2.100	2.521
4	INTERNATIONAL JOURNAL OF ENVIRONMENTAL RESEARCH AND PUBLIC HEALTH	106	2.061	2.849
5	BMJ OPEN	101	1.964	2.496
6	BMC HEALTH SERVICES RESEARCH	78	1.517	1.987
7	PREHOSPITAL AND DISASTER MEDICINE	45	0.875	1.315
8	JOURNAL OF MEDICAL INTERNET RESEARCH	38	0.739	5.034
9	PUBLIC HEALTH	38	0.739	1.774
10	SCIENCE OF THE TOTAL ENVIRONMENT	35	0.681	6.551

are 14 journals with 20–39 papers, and the total number of journals is 1,716. This shows that journals related to public health emergency management research are relatively scattered. Among the seven journals with more than 40 papers, the impact factors of journals are all higher, and 50% of them are >2.4, which indicates that many authoritative journals in academic circles are interested in the research of public health emergency management.

Analysis of the Cooperation Characteristics of the Issuing Country, Institutions, and Author

VOSviewer can draw national cooperation networks, institutional cooperation networks, and author cooperation networks and interpret the map to understand the different levels of cooperation in public health emergency management, to find the core countries, institutions, and individuals in the field. **Figure 2** shows the map of cooperation among different countries, with 92 nodes and 1,725 links, which clearly shows that scholars in many countries attach great importance to public health emergency management research, and there is more cooperation among countries. In terms of the number of published papers, the United States obtains the most research results in the field of public health emergency management, with 2,120 papers published, accounting for 41% of the total number of published papers. In addition, its intermediary centrality is 0.02, which indicates that although the United States has a large number of papers, it lacks highly cited articles. There is

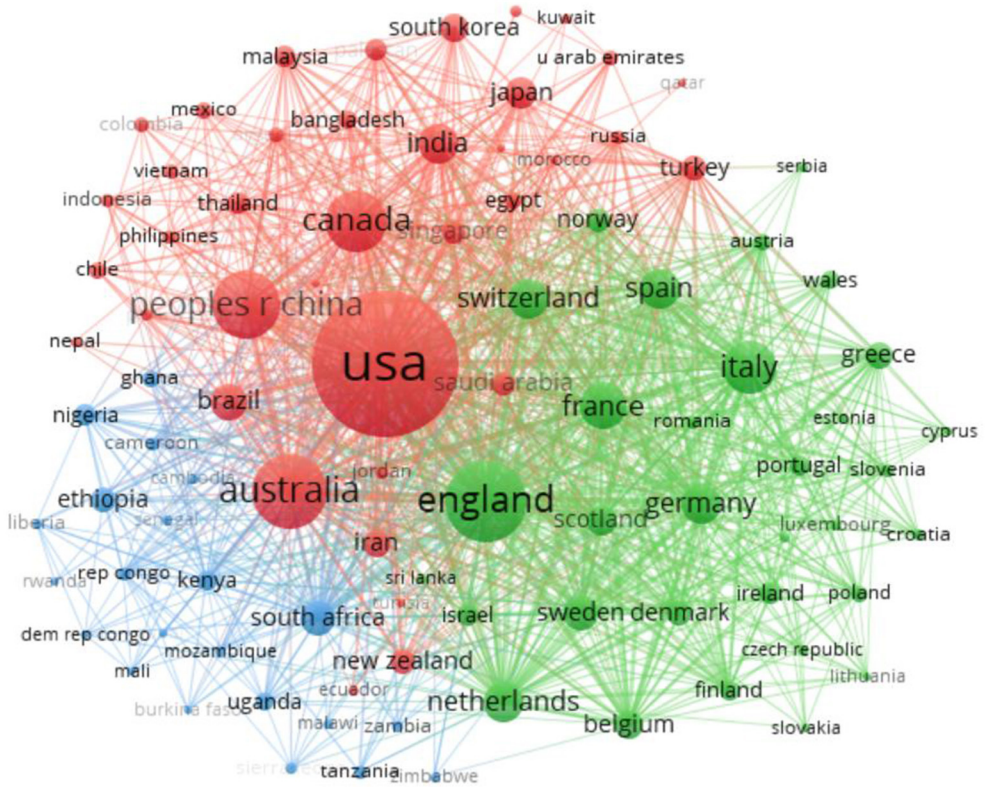


FIGURE 2 | National atlas of research papers on public health emergency management from 2007 to 2020.

more cooperation between the United States and China, while European countries take the United Kingdom as the center, and South Africa is relatively important in African countries, the cluster cooperation formed among many countries is close, and the network system is strong. In addition, the UK, Australia, China, Canada, and other countries have also published many high-impact papers in this field. The number of published papers is proliferating, and the intermediary centrality is constantly improving, indicating that an increasing number of countries have begun to pay attention to research in the field of public health emergency management.

Table 2 shows the top 10 research institutions in terms of intermediary centrality and frequency, including seven in the United States, one in the United Kingdom, and one in Australia. The institutions with the highest intermediary centrality and frequency are all from the United States, and among the top 10 institutions, the United States monopolizes seven. The United States has been in the leading position in this field based on its inception and duration of research. The top five institutions are Harvard University, the Centers for Disease Control and Prevention, the University of Sydney, the University of British Columbia, and the University of California, Los Angeles (UCLA). These institutions have solid academic strengths. Harvard University has world-class academic influence in the life sciences, natural sciences, and sociology. The United States Centers for Disease Control and Prevention (CDC) is the first federal health organization founded in the United States, focusing on the development and application of disease prevention and control, environmental health and other activities to improve people's health. The University of Sydney ranks 20th in the world in life medicine. The University of British Columbia enjoys a high reputation in management and hygiene, and UCLA is a world leader in medicine and business management.

TABLE 2 | Top 10 institutions of literature output from 2007 to 2020.

Number	Institution	Between centrality	Frequency
1	Harvard Univ	0.13	106
2	Ctr Dis Control & Prevent	0.12	123
3	Univ Sydney	0.09	87
4	Univ British Columbia	0.09	65
5	Univ Calif Los Angeles	0.09	42
6	Univ Calif Irvine	0.09	14
7	Univ Massachusetts	0.08	14
8	Univ Washington	0.07	92
9	WHO	0.07	78
10	Columbia Univ	0.07	65

The development and evolution of disciplines benefit from the contribution of researchers, and researchers, as endogenous forces, can promote the development of disciplines. Through the authors' analyses, we can understand the general situation of the papers issued by the authors in this field and then realize the tracking and cooperative research in this field. **Figure 3** shows the author collaboration network map in the field of public health emergency management; the top five authors in terms of published papers are Frederick M (10 papers), C Norman Coleman (6 papers), Carlos A (6 papers), Falko F Sniehorta (5 papers), and Amir Khorrammanesh (5 papers). The top five cited authors are Huang Cl (70 times), Moher D (65 times), Van Den B (63 times), Zhou F (52 times), and Liu Y (49 times). Each author is represented by a dot in the graph, and the collaboration between authors is represented by a line between nodes. From the map, we can see that several research cooperation teams have been formed, especially the team with Professor Amir Khorrammanesh as the core, which has carried out many cooperative research and established cooperative relations with many scholars. The overall level of cooperation among authors is low, and most researchers are individuals with little cross-team communication.

ANALYSIS ON HOTSPOTS OF PUBLIC HEALTH EMERGENCY MANAGEMENT

Literature Co-citation Analysis and Knowledge Base Identification

Literature co-citation analysis is a research method to measure the degree of relationship between literature, exploring the development and evolution. There were 218,552 citations in 5,143 articles on public health emergency management collected in this study; the minimum number of citations was set as 12, and 112 citations were finally obtained. For the 112 selected studies, the modular layout and clustering method of VOSviewer were used to construct a visual map of the literature co-citation network, as shown in **Figure 4**.

In **Figure 4**, 112 nodes represent 112 studies, and the distance between nodes represents the similarity of the literature. The visualization results showed that 112 citations were automatically divided into three clusters according to the VOSviewer clustering method. The knowledge base of public health emergency management was divided into three knowledge groups by merging and summarizing the topics of every cluster: global disease and health services (knowledge group 1), guidelines for opioid use (knowledge group 2), and clinical characteristics of patients with the COVID-19 pneumonia (knowledge group 3).

1) Knowledge base 1: global disease and health services

   Knowledge group 1 focused on global diseases and health services. In 2009, Duffy et al. found for the first time that ZIKV spread outside Africa and Asia (14, 15), which helped clinicians and public health officials to realize the risk of further expansion. In 2014, Aylward et al. introduced forward-looking thinking to predict the Ebola virus (16) and proposed increasing control measures, which effectively reduced the virus's mortality. Emerging infectious diseases are a heavy burden on the global economy and public health, and scientific monitoring is needed (17). Walsh pointed out that the core competence of disaster medicine and public health is to develop a set of clear and concise training standards for health professionals to respond to major public health emergencies effectively (18). Damschroder proposed to put the research results of health services into practice and promote the implementation of a comprehensive scientific framework (19). In 2009, Harris combined electronic data capture with public health services for the first time (20), aiming to rapidly develop and deploy electronic data capturing tools to facilitate clinical and translational research.

2) Knowledge base 2: guidelines for opioid use

   Knowledge group 2 focused on guidelines for opioid use. Adams proposed early management guidelines for patients with acute ischemic stroke and pointed out that further research on the treatment of acute ischemic stroke is needed (21). Hacker tested the alteplase treatment in stroke patients, and the results showed that the treatment was more often associated with symptomatic intracranial hemorrhage (22). Brummett found that continuous opioid use was common after minor and major surgical procedures (23) and pointed out that new continuous opioid use will bring a previously underestimated surgical complication, worthy of further understanding. To effectively evaluate the effectiveness and risk of long-term use of opioids for the treatment of chronic pain, Chou found that the effectiveness of long-term opioid treatment to improve chronic pain could not be determined through randomized trials and observations (24), and excessive opioid treatment would lead to a risk of dependence. The United States Centers for Disease Control and Prevention has updated opioid prescription guidelines for chronic pain, to improve the safety and effectiveness of pain treatment and reduce the risks associated with long-term opioid treatment (25, 26).

3) Knowledge base 3: clinical characteristics of patients with COVID-19 pneumonia

   Knowledge group 3 focused on the clinical characteristics of patients with COVID-19 pneumonia. In 2020, Huang et al. collected and analyzed the data of patients infected with COVID-19 (27) and found that most of the infected patients were male. All patients had pneumonia, abnormal chest computed tomography, and complications, which revealed an urgent need to fill a major gap in the understanding of epidemiology in further studies. Guan found that the median age of COVID-19 patients was 47 years, and the most common symptoms were fever and cough, and the vast majority of patients developed lymphoma (28). Zhou described the risk factors leading to death and the detailed clinical disease course and that the long-term shedding of the virus justifies future isolation of infected patients and optimal antiviral interventions (29). Hoffmann proposed insights into which cytokines in COVID-19 might provide viral transmission and identified potential targets for antiviral intervention (30). In 2020, Wu, for the first time, systematically summarized the major epidemiology and clinical findings of all COVID-19 cases reported in the Chinese mainland (31). He also reported

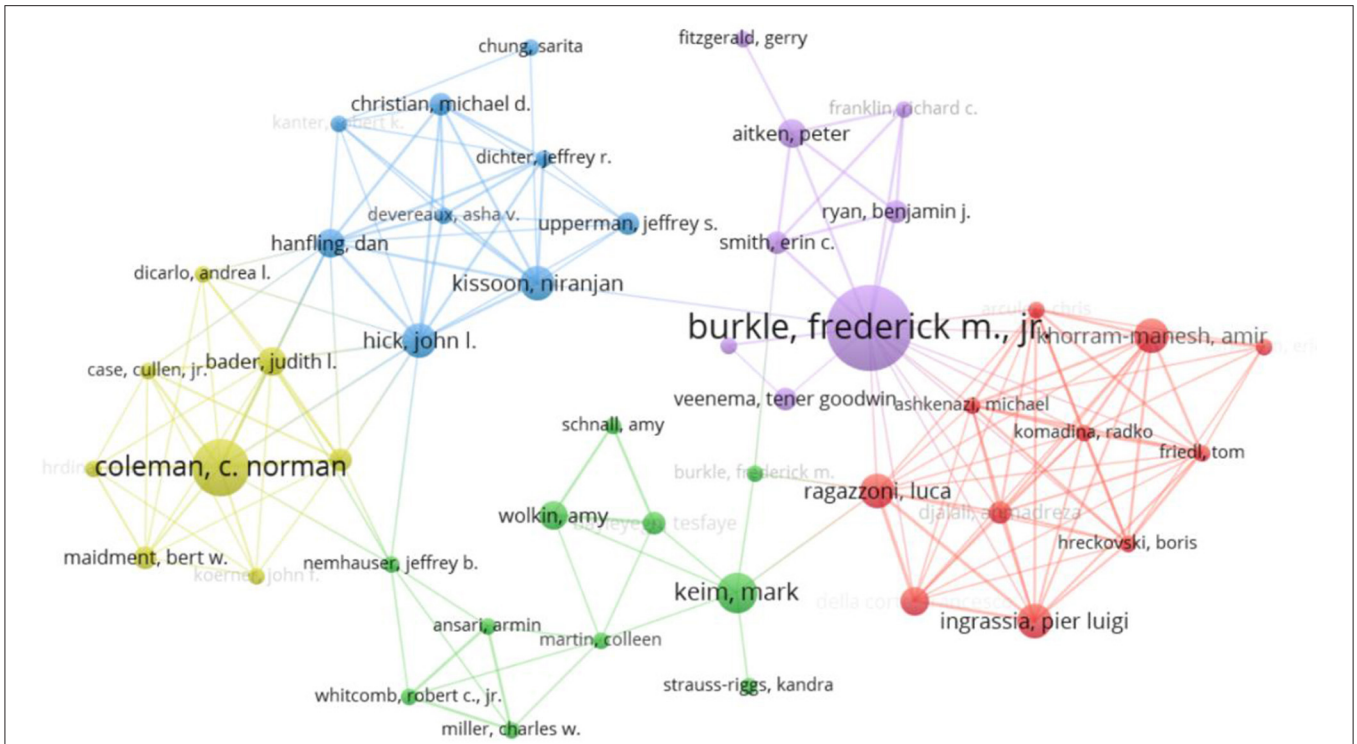


FIGURE 3 | Cooperation network of authors in public health emergency management.

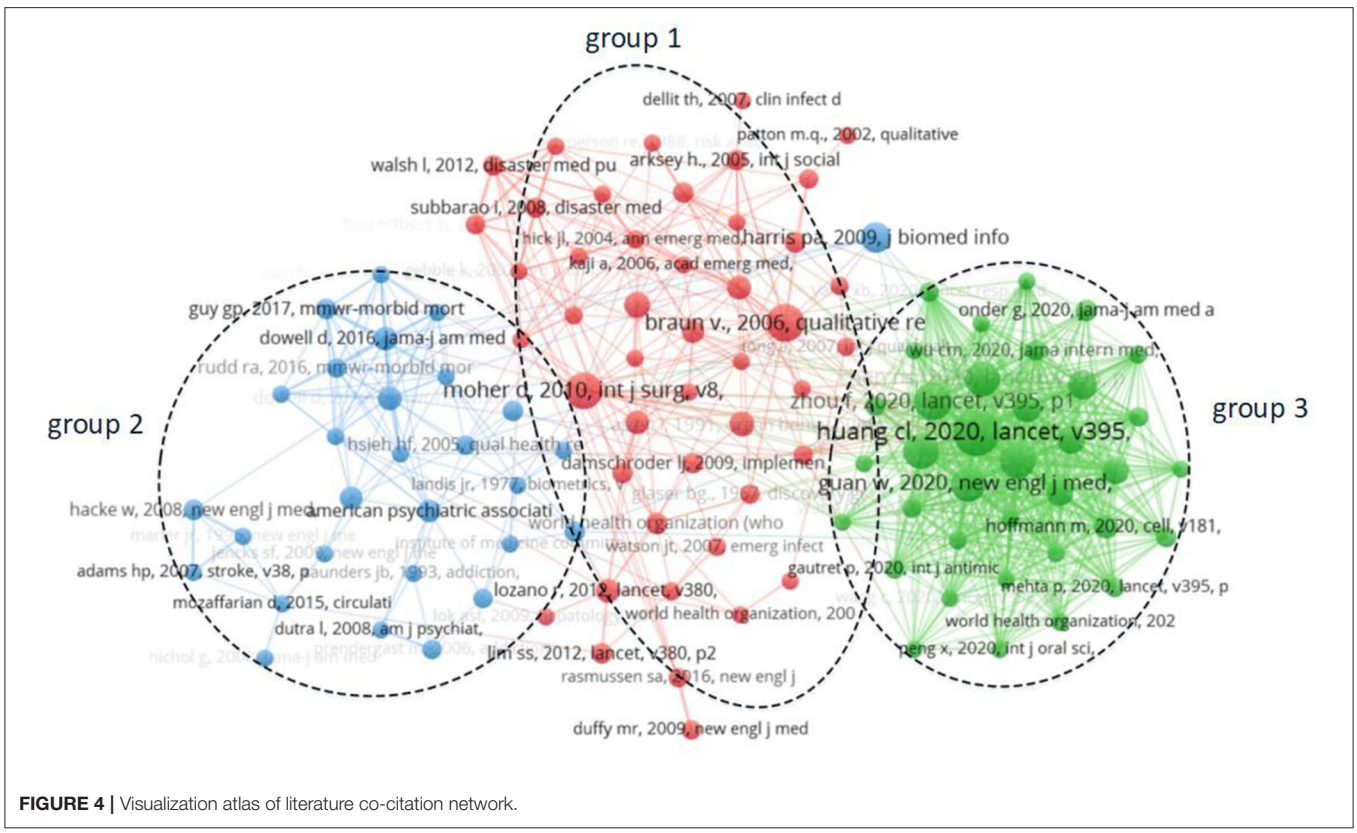


FIGURE 4 | Visualization atlas of literature co-citation network.

TABLE 3 | Common word matrix of high-frequency keywords (part).

Rank	Keywords	Frequency	Rank	Keywords	Frequency
1	Public health	347	9	Knowledge	44
2	COVID-19	347	10	Prevention	43
3	Epidemiology	168	11	Risk assessment	43
4	Disaster	62	12	Emergency management	43
5	Emergency department	54	13	Climate change	42
6	Health policy	54	14	Education	40
7	Primary care	51	15	Emergency preparedness	40
8	Management	50	16	Mental health	39

case trends in response to the government's attempts to control the infection, emphasizing that aggressive investment in public health infrastructure is essential for an effective response to outbreaks, the continued improvement of international surveillance, cooperation, coordination, and communication on this pandemic, which will contribute to a better response to new threats to public health.

Keywords Frequency Statistics and Co-occurrence Matrix

Keywords can well reflect the main content of the paper and are highly generalized and concise of the research topic. High-frequency keywords usually reflect current issues and frontier trends in a specific research field, so the statistical analysis of literature keywords can quickly and effectively understand the research hotspots in this field. Bibexcel was used to analyze the keywords of the published literature through keyword frequency analysis technology, and keywords with similar meanings were merged, keywords unrelated to this study were eliminated, and keywords with frequencies $\geq$15 were selected as high-frequency keywords for further analysis. **Table 3** lists the top 20 keywords.

Keyword Co-occurrence Analysis and Research Hotspot Identification

Keyword co-occurrence analysis is a method that uses statistical methods to calculate the frequency of co-occurrence of keywords in the same document, obtains a co-occurrence matrix, and then converts the co-occurrence matrix into a co-occurrence network (32). This study systematically combs all the keywords of 5,143 articles. It generates the co-word matrix by Bibexcel, utilizing the modular clustering algorithm of VOSviewer to analyze the co-occurrence of 129 keywords and obtain the visual map of the keyword co-occurrence network and the visual map of the keyword co-occurrence cluster, as shown in **Figures 5**, **6**.

It can be seen from the visualization results in **Figure 5** that the co-occurrence network of 129 keywords forms three clusters. Three research hotspots in the field of public health emergency management are obtained by summarizing the literature topics of each cluster in combination with citation analysis, namely, disaster prevention and emergency medical services (hotspot 1), including public health, emergency preparedness, disaster planning, health policy, and emergency medical services. Hotspot 2 includes the outbreak and management of infectious diseases in Africa, including epidemiology in Africa, management, treatment, etc. Emergency management under the COVID-19 pneumonia epidemic (hotspot 3), including keywords like COVID-19, China, attitude, management, and more. It can be seen from **Figure 6** that public health, COVID-19 pneumonia, and epidemiology are becoming the research focus of public health emergency management in the yellow area, and other research can be regarded as being carried out around these three cores.

1) Research focus 1: disaster prevention and emergency medical services

   Hotspot 1 focused on disaster prevention and emergency medical services. Abir et al. suggested that professional associations could use their member networks to collect survey data promptly to inform best practices during and after public health emergencies (33). In 2018, Acosta et al. argued that the network of community-based organizations has a flexible range of partner services and that coordinating community and public health partnerships can effectively contribute to disaster recovery (34), which provides a new way to deal with major public health emergencies. Adini et al. suggested that familiarity with guidelines and preparedness assessments affects healthcare managers' perceptions of their ability to prepare for and manage pandemic influenza (35). Abdullelah et al. believed that strengthening nurses' knowledge of core competency areas can contribute to disaster recovery and proposed the involvement of stakeholders in the adaptation process in response to the Australian heatwave disaster (36). In 2014, Aung et al. proposed the traceability of food supply chains for the first time to effectively ensure food quality and safety, aiming to help consumers achieve confidence (37). In 2010, Huang et al. proposed for the first time that Web2.0 and Internet social network are new tools for disaster management and established an Internet-based emergency response system to prevent disasters (38), which put forward new measures for public health emergency management from the perspective of big data networks.
2) Research hotspot 2: outbreak and management of infectious diseases in Africa

   Hotspot 2 focused on the outbreak and management of infectious diseases in Africa. Africa's economy is backward, healthcare is extremely scarce, and how to deal with the spread of infectious diseases is gradually becoming the focus

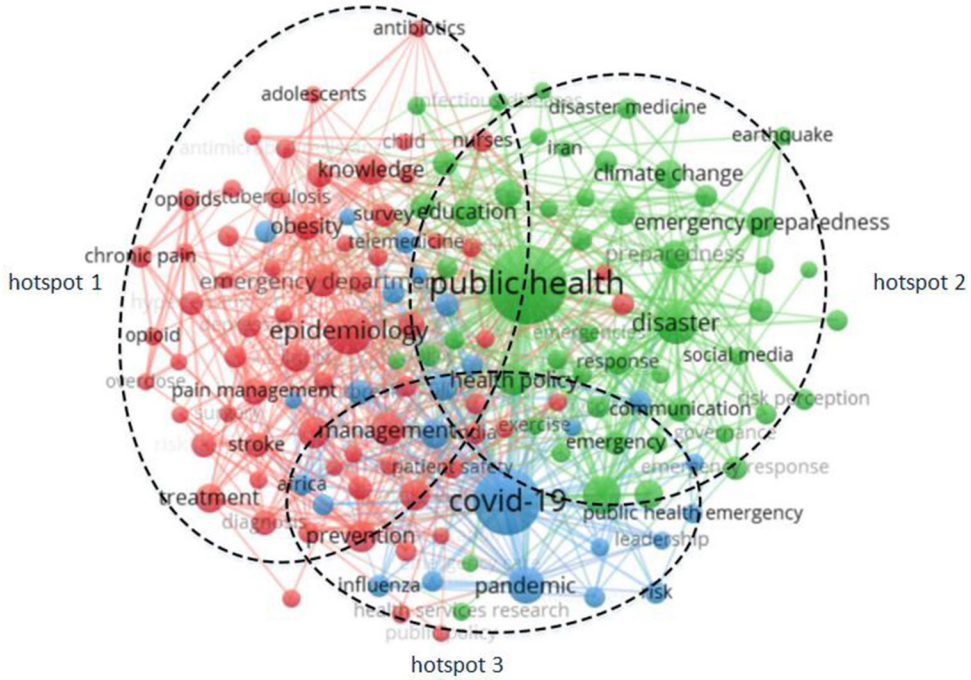


FIGURE 5 | Keywords co-occurrence network visualization map.

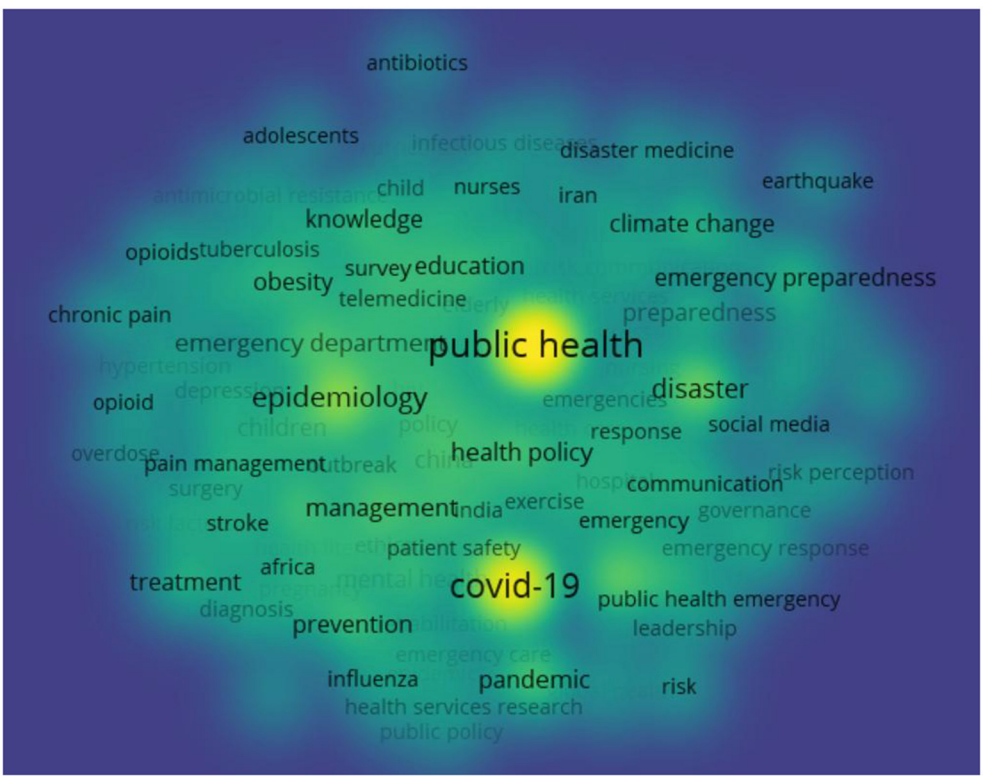


FIGURE 6 | Keywords co-occurrence clustering density visualization map.

of many scholars. Chopra et al. argued that South Africa needs talented leadership, vision, and commitment to meet new challenges and address public health emergencies (39). In 2019, Bedford et al. put forward a new concept of the epidemic (40), which evolved from a crisis response of discrete outbreaks to an integrated cycle of preparedness, response, and recovery, which required improving countries' public health emergency management capacity. Critchley et al. suggested that due to the convergence of epidemics in sub-Saharan Africa, research should prioritize addressing the interaction among TB, diabetes, and HIV (41). Migliori et al. argued that with the current global trend of MDR-TB increasing, existing interventions, public health systems, and TB programs must be significantly strengthened, and political and funding commitments are essential to curb the spread of MDR-TB (42). Peyre et al. studied the different economic impacts caused by Rift Valley Fever and proposed that early detection and rapid response should be implemented to help decision-makers make choices related to its management (43).

3) The research hotspot 3: emergency management under COVID-19 pneumonia epidemic

Hotspot 3 focused on emergency management during the COVID-19 pneumonia epidemic. The spread of COVID-19 globally has caused huge casualties and property losses, destroyed public health order, and caused great social panic. Based on this background, many countries and institutions have conducted in-depth research. Al-Shamsi et al. pointed out that many cancer patients are at higher risk of infection due to low immune function and proposed telemedicine to help patients reduce the number of visits and exposure risks (44). In 2020, Chan et al. argued that in addition to a top-down health emergency and disaster risk management, bottom-up individual and household measures are essential for COVID-19 prevention and emergency response (45), which is conducive to raising public awareness of self-protection. In the face of the new epidemic, governments have taken a series of rapid, comprehensive, and effective prevention and control measures, established and improved the public health emergency response system, especially the emergency reserve system of medical supplies, and promoted the establishment of international cooperation projects to respond to international public health emergencies jointly (46–48). In 2020, Zhang et al. believed that risk communication was essential to public health emergency management and constructed a simplified government-expert-public risk communication model to illustrate the important role of an effective risk communication collaboration network in dealing with the COVID-19 epidemic (49), which provided new countermeasures and suggestions for public health emergency management.

Analysis on the Evolution Trend of Public Health Emergency Management

To better understand the development trend in the field of public health emergency management in recent years, this paper presents a time zone map of keywords in public health emergency management research based on the analysis map of keyword co-occurrence cooperation network (**Figure 7**). The time division was set as 1 year, the node type was set as a keyword, and the knowledge map was drawn using the pathfinder algorithm, which resulted in 509 keywords and 720 node connections. The size of the nodes in the graph indicates the frequency of keywords, and the connections indicate the co-word relationships between keywords. With the help of the update and interaction of articles presented by the keyword time zone map, the evolution process of public health emergency management research from 2007 to 2020 is revealed, and the migration path of research hotspots can be clearly understood through the time zone map.

Public health emergency management initially focused on health research, such as cardiovascular disease (2007–2009). Cardiovascular disease refers to a series of diseases caused by heart and vascular diseases, including coronary heart disease, hypertension, and cerebrovascular disease, among others, with the characteristics of high morbidity, high disability rate, high recurrence rate, high mortality rate, and many complications, coupled with the limited medical and health technology at that time, according to the World Health Organization. Among the major diseases threatening human health, cardiovascular disease has the highest mortality rate, which has become a major global health problem and poses serious challenges to the world. This quickly became a research hotspot at that time.

With the deepening of research, the focus of research in this field has shifted to emergency management and risk assessment of public health emergencies (2010–2018). Since the twenty first century, the frequency of major public health emergencies and their derivative crises has been increasing, and there is an urgent need to do a good job in public health emergency management and risk assessment. Pre-disaster prevention and early warning mechanisms have been put in the core position, and the comprehensive assessment of public health risks improves the ability to deal with major public health emergencies.

In recent years, public health emergency management has focused on the COVID-19 epidemic (2019–2020). The COVID-19 epidemic is the most serious public health crisis in human history, which has a fundamental impact on the global healthcare system and the national emergency management system, causing huge casualties and property losses. Many scholars at home and abroad have carried out in-depth research on the background, evolution path, response measures, and future development direction. It is emphasized that the major epidemic prevention and control system and mechanism and the national public health emergency management system should be constantly improved. International cooperation should be strengthened to combat the COVID-19 epidemic and other major public health emergencies, and public health emergency management is increasingly showing a trend of diversification.

DISCUSSION

In the past 5 years, the relevant literature on public health emergency management has been increasing. The life cycle theory shows that an event will go through gestation to

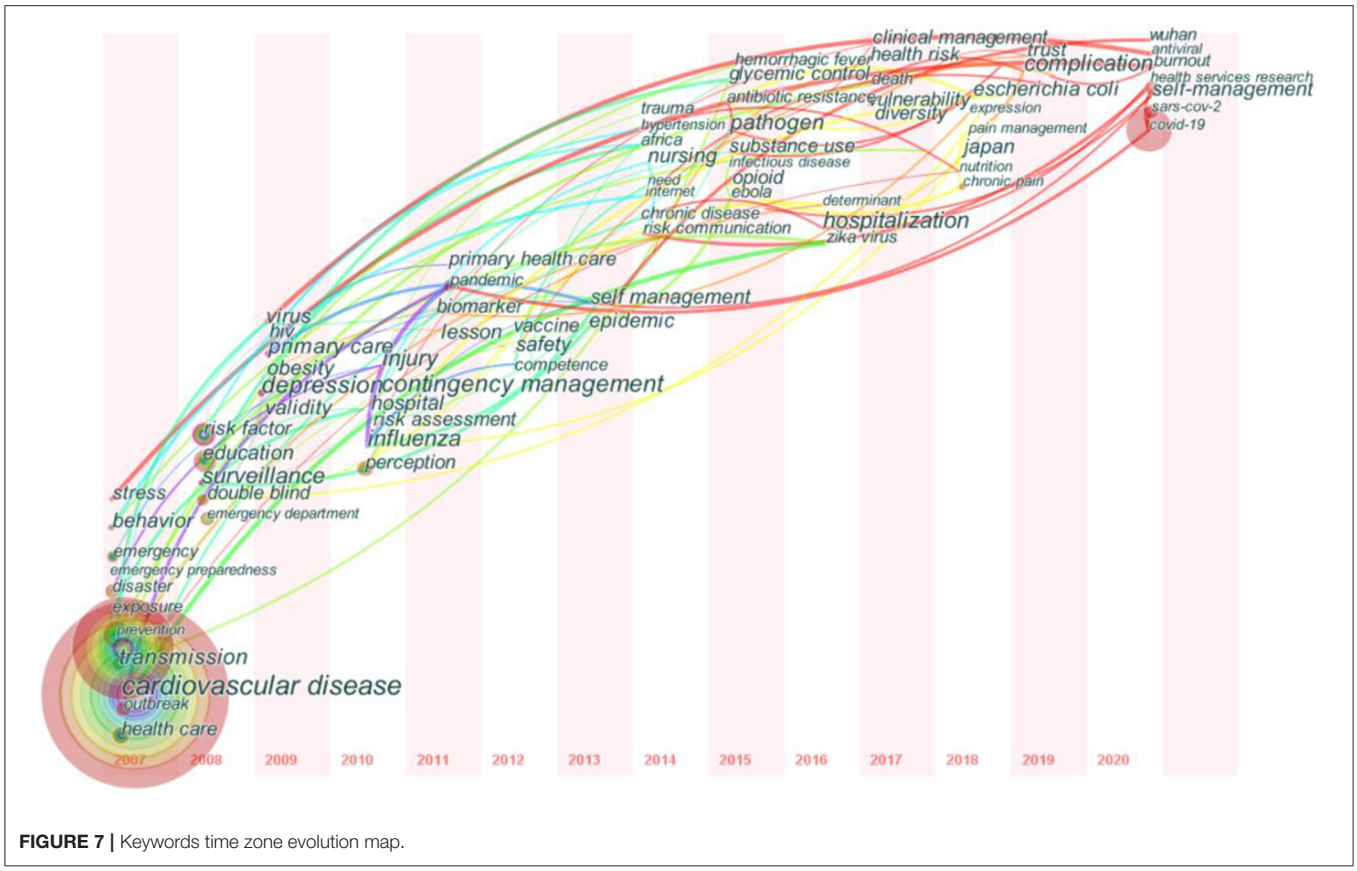


FIGURE 7 | Keywords time zone evolution map.

extinction, and each stage has different characteristics (50). Accordingly, public health emergency management research will also experience a development process from less to more, from rising to falling. This study explores the life cycle of public health emergency management. According to the literature and development trends, three periods were identified: the initial exploration period, the continuous development period, and the outbreak. Although it is impossible to accurately predict the future life cycle of public health emergency management, this research remains an important topic, and it has a broad application prospect and theoretical value from the development trends.

In recent years, with the advancement of globalization, the frequency and complexity of public health emergencies have been increasing. Various secondary and derivative problems caused by the COVID-19 epidemic have also become a major global public health emergency caused by compound disaster risk, which has brought tremendous impact and challenges to the construction of emergency management systems and capacity improvement of governments. Emergency management does not only refer to the management of response activities such as preventive preparedness, monitoring, and early warning, disposal and rescue, recovery, and reconstruction before, during, and later stages of an emergency, and the whole life cycle of an emergency, but also to the system's ability to respond quickly to emergencies and perform tasks on time. Good emergency management can effectively deal with public health emergencies, which will help countries to establish and improve public health emergency management system and international emergency management cooperation mechanism, and improve the international community's ability to respond to major public health emergencies.

In the initial exploration period, theoretical research on this subject was in its early stage, and the average annual number of articles was <200. During this time, relevant research mainly focused on basic medical health research, such as stroke (51), influenza (52), cardiovascular disease (53), and so on. However, during this stage, the research field had certain limitations. Specifically, the high mortality rate of these diseases was a huge obstacle to be overcome in the medical field. In addition, the medical health level was low at that time, researchers focused more on public health and studied how to overcome these diseases. The relevant research on public health emergency management was relatively shallow.

In the continuous development period, the average annual number of articles was more than 200, and researches began to focus on emergency management and risk assessment of public health emergencies (54). With the excessive pursuit of high-speed economic growth, human beings have brought a serious burden to nature, the ecological environment has been seriously damaged, the frequency of major public health emergencies and their derivative crises are increasing, coupled with the impact of

traditional public health events, scholars began to pay attention to emergency management and risk assessment. Kebede et al. believed that we should focus more on developing hospital managers, not just on enhancing medical and public health skills, recognizing the importance of management capacity to achieve sustainable development (55). Geographic information system can effectively reveal the differences of regional medical services, especially for primary health care and clinical health (56), and the use of health information exchange network can effectively evaluate regions medical health level (57). With the further implementation of telemedicine technology, the spatial distance is greatly reduced, which brings great convenience to the emergency management of public health emergencies (58). For low- and middle-income countries, we can assess current and planned pharmacovigilance activities, identify gaps and the most urgent pharmacovigilance priorities at national and international levels, and define the elements of a sustainable global pharmacovigilance strategy (59). Through pre disaster prevention, establishing and improving the early warning mechanism and further relying on science and technology, we can effectively improve the global ability to respond to major public health emergencies.

In the outbreak period, public health emergency management has focused on the COVID-19 epidemic. The COVID-19 epidemic, which appeared in 2019, has been spreading rapidly, with high uncertainty and high mortality rate. It has spread to most countries in the world, and has brought huge casualties and property losses, which posed severe challenges to global public health, and many researchers have turned to the COVID-19 epidemic research. Deshmukh et al. systematically summarized the updated epidemiology, causes, clinical manifestation and diagnosis, as well as prevention and control of the novel coronavirus SARS-CoV-2, which is essential to both manage the current pandemic and to conceive comprehensive measures to prevent such outbreaks in the future (60). Communities are central to the practice of public health emergency preparedness and response (61), it is important to identify the source of infection at the community level as soon as possible to block the transmission path of the virus to prevent the spread of the pandemic. The implementation of grid management in the community and the adoption of precise management and control measures to reduce unnecessary personnel movement can effectively reduce the risk of pandemic spread, and improving community disaster resilience are an effective method for coping with such a public health emergency (62). By analyzing the consequences of exclusionary othering in public health, Tallarek et al. proposed to move toward inclusionary and diversity-sensitive public health (63). Public health emergencies will lead to public health crisis, government risk communication plays a key role in responding to public health emergencies (64). Governments should timely disseminate and update information related to the epidemic, stabilize public sentiment, strengthen public opinion and epidemic prevention and control, and implement hierarchical management in key epidemic areas and urban agglomerations. In the face of public health emergencies, there will be deficiencies in biosafety, food safety, public health investment and emergency system construction (46), the world should constantly improve the system of emergency reserve medical supplies, promote the establishment of international cooperative programs to jointly deal with public health emergencies of international concern in the future. Public health emergency management is increasingly showing a trend of diversification.

Finally, this study combined the data and literature analysis to point out possible future research directions: from the research of the COVID-19 pneumonia epidemic to the research of general major public health emergencies, thinking and remodeling of the national public health emergency management system, and exploring the establishment of an efficient international emergency management cooperation mechanism.

LIMITATIONS

The main limitation of this study is its focus on the published literature in English. Consequently, relevant information in other languages may be missing. The criteria used to narrow the selection of included publications enabled the authors to access eligible data and a feasible number of publications to handle the content analysis and to perform the review. However, the criteria used may have been too selective, resulting in missing information. In addition, in the selection of database, this study selects the representative Web of Science as the literature collection database, missing other databases. These limitations can be further addressed as a part of the future research.

CONCLUSIONS AND RECOMMENDATIONS

In this study, CiteSpace and VOSviewer, two authoritative scientometrics analysis software, were used to visually analyze 5,143 articles on public health emergency management in the core database of Web of Science. Based on bibliometric analysis methods, such as frequency analysis of keywords, analysis of the occurrence of keywords, and analysis of the time zone of keywords, this article combines the research status and hotspots in the field of emergency management in public health. It points out the following research direction and corresponding proposals. First, the regional distribution of scientific research forces in public health emergency management is unbalanced. The United States, the United Kingdom, Australia, and China are the top four countries in public health emergency management, accounting for 73.7% of the total literature. Among them, the United States carried out research on public health emergency management earlier, published the largest number of papers in this field, and had a larger impact coefficient, which was in the core position in this field. China ranks fourth in terms of the number of papers issued and has developed rapidly in recent years, with a large fund investment. Although the public health emergency management originated in developed countries, research on developing countries such as China, South Africa, and India is gradually increasing. In addition, the degree of cooperation between research institutions and

core authors in this field is low, the number of high-yielding authors is small, most researchers are individuals, and cross-team communication is minimal. Therefore, collaboration is necessary to deepen cooperation and cultivate more research centers with vast influence.

Second, public health emergency management has shifted from focusing on post-disaster recovery to emphasizing pre-disaster prevention. With the acceleration of globalization, many public health emergencies have brought great threats and losses to people worldwide. An increasing number of scholars have begun to pay attention to pre-disaster prevention, resolutely implement the health policy of prevention first, and establish awareness of periodic risk prevention and control. They are establishing an Internet-based emergency response system, training a large number of professional public health personnel, and strengthening the public health infrastructure, which is aimed at the rapid response to major public health emergencies and disaster prevention.

Third, to fully understand the current status of research on public health emergency management, this study selected software especially suitable for bibliometric analysis, including CiteSpace, vosviewer, Netdraw, etc., conducting a visualization analysis based on the relevant research obtained from the Web of Science database, and determining the number of research studies, the major countries publishing on this topic, and the journal distribution. Then, keyword co word analysis, social network analysis and cluster analysis are selected to clarify the development trend and research theme of public health emergency management research hotspots. Finally, by reading and summarizing a large number of relevant literature, we have a good grasp of public health emergency management, and put forward possible future research directions, which fills the gap in public health emergency management and provides a framework for future research. At the same time, there are some limitations in. In the selection of database, this study selects the representative Web of Science as the literature collection database, other databases may have been missed. These limitations can be further addressed as a part of the future research.

Fourth, the construction of major epidemic prevention and control systems, mechanisms, and national public health emergency management systems have attracted much attention. The COVID-19 epidemic sweeping the world has seriously impacted the healthcare systems and emergency management systems of countries worldwide, causing massive casualties and property losses. We should strengthen epidemic prevention and control, innovate major epidemic prevention and control measures in the system and mechanism, clarify the prominent importance of building a major epidemic prevention and control system and mechanism and national public health emergency management system, and give full play to the main role of the government, market, and society; establish and improve an efficient monitoring and early warning system and emergency support system; and improve emergency plans and other related systems, which will improve the world's ability to detect public health emergencies on time, make scientific decisions, and jointly prevent and control them.

Fifth, the international emergency management cooperation mechanism for major public health emergencies needs to be further improved. Major public health emergencies are sudden, complex, and unbounded, which will produce a global "ripple effect." The COVID-19 epidemic has extremely exposed the fragility of the international emergency management cooperation mechanism. It is necessary to strengthen the consensus of the "community of human destiny," to improve the ability of the international community to respond to major public health emergencies. Countries should not shirk their responsibilities, adhere to the guiding principles of multilateral cooperation to jointly combat the epidemic, and promote the establishment of cross-regional, cross-sectoral, and cross-sectoral emergency management procedures and safeguards to give full play to the inherent advantages of the international emergency management cooperation mechanism.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

LY and XF contributed to the analysis and interpretation of data for the study and wrote the first draft of the manuscript. XF designed the framework for this study. JZ contributed to the acquisition of data for this study. All authors approved the final manuscript.

FUNDING

This study was supported by General Project of the National Natural Science Foundation of China (grant no. 71971003) and the Major Project of the National Social Science Funding of China (grant no. 20ZDA084).

REFERENCES

1. Winslow CE. The untilled fields of public health. *Science.* (1920) 51:23–33. doi: 10.1126/science.51.1306.23
2. Khan Y, O'Sullivan T, Brown A, Tracey S, Gibson J, Généreux M, et al. Public health emergency preparedness: a framework to promote resilience. *BMC Public Health.* (2018) 18:1–16. doi: 10.1186/s12889-018-6250-7
3. Gostin LO, Katz R. The International Health Regulations: the governing framework for global health security. *Milbank Q.* (2016) 94:264–313. doi: 10.1111/1468-0009.12186
4. Lo STT, Chan EYY, Chan GKW, Murray V, Abrahams J, Ardalan A, et al. Health emergency and disaster risk management (Health-EDRM): developing the research field within the Sendai framework paradigm. *Int J Disaster Risk Sci.* (2017) 8:145–9. doi: 10.1007/s13753-017-0122-0

5. Moore S, Mawji A, Shiell A, Noseworthy T. Public health preparedness: a systems-level approach. *J Epidemiol Commun Health.* (2007) 61:282–6. doi: 10.1136/jech.2004.030783
6. Shoaf KI, Rottman SJ. The role of public health in disaster preparedness, mitigation, response, and recovery. *Prehosp Disaster Med.* (2000) 15:18–20. doi: 10.1017/S1049023X00025243
7. Singleton CM, Corso L, Koester D, Carlson V, Bevc CA, Davis MV. Accreditation and emergency preparedness: linkages and opportunities for leveraging the connections. *J Public Health Manage Pract.* (2014) 20:119–24. doi: 10.1097/PHH.0b013e3182a9dbd8
8. Patriti A, Baiocchi GL, Catena F, Marini P, Catarci M. Emergency general surgery in Italy during the COVID-19 outbreak: first survey from the real life. *World J Emerg Surg.* (2020) 15:1–7. doi: 10.1186/s13017-020-00314-3
9. Qian K, Yahara T. Mentality and behavior in COVID-19 emergency status in Japan: influence of personality, morality and ideology. *PloS ONE.* (2020) 15:e0235883. doi: 10.1371/journal.pone.0235883
10. Mihai FC. Assessment of COVID-19 waste flows during the emergency state in Romania and related public health and environmental concerns. *Int J Environ Res Public Health.* (2020) 17:5439. doi: 10.3390/ijerph17155439
11. Chen C. CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. *J Am Soc Inform Sci Technol.* (2006) 57:359–77. doi: 10.1002/asi.20317
12. Liu Z, Yin Y, Liu W, Dunford M. Visualizing the intellectual structure and evolution of innovation systems research: a bibliometric analysis. *Scientometrics.* (2015) 103:135–58. doi: 10.1007/s11192-014-1517-y
13. Waltman L, Van Eck NJ, Noyons EC. A unified approach to mapping and clustering of bibliometric networks. *J Informetr.* (2010) 4:629–35. doi: 10.1016/j.joi.2010.07.002
14. Duffy MR, Chen TH, Hancock WT, Powers AM, Kool JL, Lanciotti RS, et al. Zika virus outbreak on Yap Island, federated states of Micronesia. *New Engl J Med.* (2009) 360:2536–43. doi: 10.1056/NEJMoa0805715
15. Rasmussen SA, Jamieson DJ, Honein MA, Petersen LR. Zika virus and birth defects—reviewing the evidence for causality. *N Engl J Med.* (2016) 374:1981–7. doi: 10.1056/NEJMsr1604338
16. WHO Ebola Response Team. Ebola virus disease in West Africa—the first 9 months of the epidemic and forward projections. *N Engl J Med.* (2014) 371:1481–95. doi: 10.1056/NEJMoa1411100
17. Jones KE, Patel NG, Levy MA, Storeygard A, Balk D, Gittleman JL, et al. Global trends in emerging infectious diseases. *Nature.* (2008) 451:990–3. doi: 10.1038/nature06536
18. Walsh L, Subbarao I, Gebbie K, Schor KW, Lyznicki J, Strauss-Riggs K, et al. Core competencies for disaster medicine and public health. *Disaster Med Public Health Prepared.* (2012) 6:44–52. doi: 10.1001/dmp.2012.4
19. Damschroder LJ, Aron DC, Keith RE, Kirsh SR, Alexander JA, Lowery JC. Fostering implementation of health services research findings into practice: a consolidated framework for advancing implementation science. *Implement Sci.* (2009) 4:1–15. doi: 10.1186/1748-5908-4-50
20. Harris PA, Taylor R, Thielke R, Payne J, Gonzalez N, Conde JG. Research electronic data capture (REDCap)—a metadata-driven methodology and workflow process for providing translational research informatics support. *J Biomed Inform.* (2009) 42:377–81. doi: 10.1016/j.jbi.2008.08.010
21. Adams HP Jr., Del Zoppo G, Alberts MJ, Bhatt DL, Brass L, Furlan A, et al. Guidelines for the early management of adults with ischemic stroke: a guideline from the American Heart Association/American Stroke Association Stroke Council, Clinical Cardiology Council, Cardiovascular Radiology and Intervention Council, and the Atherosclerotic Peripheral Vascular Disease and Quality of Care Outcomes in Research Interdisciplinary Working Groups: the American Academy of Neurology affirms the value of this guideline as an educational tool for neurologists. *Stroke.* (2007) 38:1655–711. doi: 10.1161/STROKEAHA.107.181486
22. Hacke W, Kaste M, Bluhmki E, Brozman M, Dávalos A, Guidetti D, et al. Thrombolysis with alteplase 3 to 4.5 hours after acute ischemic stroke. *N Engl J Med.* (2008) 359:1317–29. doi: 10.1056/NEJMoa0804656
23. Brummett CM, Waljee JF, Goesling J, Moser S, Lin P, Englesbe MJ, et al. New persistent opioid use after minor and major surgical procedures in US adults. *JAMA Surg.* (2017) 152:e170504. doi: 10.1001/jamasurg.2017.0504
24. Chou R, Turner JA, Devine EB, Hansen RN, Sullivan SD, Blazina I, et al. The effectiveness and risks of long-term opioid therapy for chronic pain: a systematic review for a National Institutes of Health Pathways to Prevention Workshop. *Ann Intern Med.* (2015) 162:276–86. doi: 10.7326/M14-2559
25. Dowell D, Haegerich TM, Chou R. CDC guideline for prescribing opioids for chronic pain—United States, 2016. *JAMA.* (2016) 315:1624–45. doi: 10.1001/jama.2016.1464
26. Guy GP Jr., Zhang K, Bohm MK, Losby J, Lewis B, Young R, et al. Vital signs: changes in opioid prescribing in the United States, 2006–2015. *MMW Morbid Mortal Weekly Rep.* (2017) 66:697. doi: 10.15585/mmwr.mm6626a4
27. Huang C, Wang Y, Li X, Ren L, Zhao J, Hu Y, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet.* (2020) 395:497–506. doi: 10.1016/S0140-6736(20)30183-5
28. Guan WJ, Ni ZY, Hu Y, Liang WH, Ou CQ, He JX, et al. Clinical characteristics of coronavirus disease 2019 in China. *N Engl J Med.* (2020) 382:1708–20. doi: 10.1056/NEJMoa2002032
29. Zhou F, Yu T, Du R, Fan G, Liu Y, Liu Z, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort study. *Lancet.* (2020) 395:1054–62. doi: 10.1016/S0140-6736(20)30566-3
30. Hoffmann M, Kleine-Weber H, Schroeder S, Krüger N, Herrler T, Erichsen S, et al. SARS-CoV-2 cell entry depends on ACE2 and TMPRSS2 and is blocked by a clinically proven protease inhibitor. *Cell.* (2020) 181:271–80. doi: 10.1016/j.cell.2020.02.052
31. Wu Z, McGoogan JM. Characteristics of and important lessons from the coronavirus disease 2019 (COVID-19) outbreak in China: summary of a report of 72 314 cases from the Chinese Center for Disease Control and Prevention. *JAMA.* (2020) 323:1239–42. doi: 10.1001/jama.2020.2648
32. Ravikumar S, Agrahari A, Singh SN. Mapping the intellectual structure of scientometrics: a co-word analysis of the journal Scientometrics (2005–2010). *Scientometrics.* (2015) 102:929–55. doi: 10.1007/s11192-014-1402-8
33. Abir M, Moore M, Chamberlin M, Koenig KL, Hirshon JM, Singh C, et al. Using timely survey-based information networks to collect data on best practices for public health emergency preparedness and response: illustrative case from the American College of Emergency Physicians' Ebola surveys. *Disaster Med Public Health Prepared.* (2016) 10:681–90. doi: 10.1017/dmp.2016.93
34. Acosta JD, Burgette L, Chandra A, Eisenman DP, Gonzalez I, Varda D, et al. How community and public health partnerships contribute to disaster recovery and resilience. *Disaster Med Public Health Prepared.* (2018) 12:635–43. doi: 10.1017/dmp.2017.130
35. Adini B, Laor D, Aharonson-Daniel L. Factors affecting preparedness and capacity to manage pandemic influenza: perceptions of healthcare managers. *Public Health.* (2014) 128:703–8. doi: 10.1016/j.puhe.2014.06.002
36. Al Thobaity A, Plummer V, Williams B. What are the most common domains of the core competencies of disaster nursing? A scoping review. *Int Emerg Nurs.* (2017) 31:64–71. doi: 10.1016/j.ienj.2016.10.003
37. Aung MM, Chang YS. Traceability in a food supply chain: safety and quality perspectives. *Food Control.* (2014) 39:172–84. doi: 10.1016/j.foodcont.2013.11.007
38. Huang CM, Chan E, Hyder AA. Web 2.0 and Internet social networking: a new tool for disaster management?-Lessons from Taiwan. *BMC Med Inform Decis Mak.* (2010) 10:1–5. doi: 10.1186/1472-6947-10-57
39. Chopra M, Lawn JE, Sanders D, Barron P, Karim SSA, Bradshaw D, et al. Achieving the health Millennium Development Goals for South Africa: challenges and priorities. *Lancet.* (2009) 374:1023–31. doi: 10.1016/S0140-6736(09)61122-3
40. Bedford J, Farrar J, Ihekweazu C, Kang G, Koopmans M, Nkengasong J. A new twenty-first century science for effective epidemic response. *Nature.* (2019) 575:130–6. doi: 10.1038/s41586-019-1717-y
41. Critchley JA, Restrepo BI, Ronacher K, Kapur A, Bremer AA, Schlesinger LS, et al. Defining a research agenda to address the converging epidemics of tuberculosis and diabetes: part 1: epidemiology and clinical management. *Chest.* (2017) 152:165–73. doi: 10.1016/j.chest.2017.04.155
42. Migliori GB, Dheda K, Centis R, Mwaba P, Bates M, O'Grady J, et al. Review of multidrug-resistant and extensively drug-resistant TB: global perspectives with a focus on sub-Saharan Africa. *Trop Med Int Health.* (2010) 15:1052–66. doi: 10.1111/j.1365-3156.2010.02581.x
43. Peyre M, Chevalier V, Abdo-Salem S, Velthuis A, Antoine-Moussiaux N, Thiry E, et al. A systematic scoping study of the socio-economic impact of

Rift Valley fever: research gaps and needs. *Zoonoses Public Health.* (2015) 62:309–25. doi: 10.1111/zph.12153
44. Al-Shamsi HO, Alhazzani W, Alhuraiji A, Coomes EA, Chemaly RF, Almuhanna M, et al. A practical approach to the management of cancer patients during the novel coronavirus disease 2019 (COVID-19) pandemic: an international collaborative group. *Oncologist.* (2020) 25:e936. doi: 10.1634/theoncologist.2020-0213
45. Chan EYY, Huang Z, Lo ESK, Hung KKC, Wong ELY, Wong SYS. Sociodemographic predictors of health risk perception, attitude and behavior practices associated with health-emergency disaster risk management for biological hazards: the case of COVID-19 pandemic in Hong Kong, SAR China. *Int J Environ Res Public Health.* (2020) 17:3869. doi: 10.3390/ijerph17113869
46. Wang X, Zhang X, He J. Challenges to the system of reserve medical supplies for public health emergencies: reflections on the outbreak of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) epidemic in China. *Biosci Trends.* (2020) 14:3–8. doi: 10.5582/bst.2020.01043
47. Li J, Li S, Cao W, Wang Z, Liang Z, Fu W, et al. Appraisal of China's Response to the Outbreak of COVID-19 in Comparison With SARS. *Front Public Health.* (2021) 9:679540. doi: 10.3389/fpubh.2021.679540
48. Nair MK, Augustine LF, Konapur A. Food-based interventions to modify diet quality and diversity to address multiple micronutrient deficiency. *Front Public Health.* (2016) 3:277. doi: 10.3389/fpubh.2015.00277
49. Zhang L, Li H, Chen K. Effective risk communication for public health emergency: reflection on the COVID-19 (2019-nCoV) outbreak in Wuhan, China. *Multidisc Dig Publ Inst.* (2020) 8:64. doi: 10.3390/healthcare8010064
50. Koval V, Prymush Y, Popova V. The influence of the enterprise life cycle on the efficiency of investment. *Baltic J Econ Stud.* (2017) 3:183–7. doi: 10.30525/2256-0742/2017-3-5-183-187
51. Suwanwela N, Koroshetz WJ. Acute ischemic stroke: overview of recent therapeutic developments. *Annu Rev Med.* (2007) 58:89–106. doi: 10.1146/annurev.med.58.070605.115306
52. Thomas JK, Noppenberger J. Avian influenza: a review. *Am J Health Syst Pharm.* (2007) 64:149–65. doi: 10.2146/ajhp060181
53. Mehra R. Global public health problem of sudden cardiac death. *J Electrocardiol.* (2007) 40:S118–22. doi: 10.1016/j.jelectrocard.2007.06.023
54. Kohn S, Barnett DJ, Galastri C, Semon NL, Links JM. Public health-specific National Incident Management System trainings: building a system for preparedness. *Public Health Rep.* (2010) 125:43–50. doi: 10.1177/00333549101250S507
55. Kebede S, Abebe Y, Wolde M, Bekele B, Mantopoulos J, Bradley EH. Educating leaders in hospital management: a new model in Sub-Saharan Africa. *Int J Qual Health Care.* (2010) 22:39–43. doi: 10.1093/intqhc/mzp051
56. Bazemore A, Phillips RL, Miyoshi T. Harnessing geographic information systems (GIS) to enable community-oriented primary care. *J Am Board Fam Med.* (2010) 23:22–31. doi: 10.3122/jabfm.2010.01.090097
57. Shapiro JS, Genes N, Kuperman G, Chason K, Clinical Advisory Committee H1N1 Working Group, New York Clinical Information Exchange, et al. Health information exchange, biosurveillance efforts, and emergency department crowding during the spring 2009 H1N1 outbreak in New York City. *Ann Emerg Med.* (2010) 55:274–9. doi: 10.1016/j.annemergmed.2009.11.026
58. Polak A, Glomb G, Guszkowski T, Jablonski I, Kasprzak B, Pekala J, et al. Telemedical system" pulmotel-2010" for monitoring patients with chronic pulmonary diseases. *Metrol Meas Syst.* (2010) 17:537. doi: 10.2478/v10178-010-0044-2
59. Olsson S, Pal SN, Stergachis A, Couper M. Pharmacovigilance activities in 55 low-and middle-income countries. *Drug Saf.* (2010) 33:689–703. doi: 10.2165/11536390-000000000-00000
60. Deshmukh V, Tripathi SC, Pandey A, Deshmukh V, Patil A, Sontakke B, et al. COVID-19: a conundrum to decipher. *Eur Rev Med Pharmacol Sci.* (2020) 24:5830–41. doi: 10.26355/eurrev_202005_21378
61. Zhang L, Zhao J, Liu J, Chen K. Community disaster resilience in the COVID-19 outbreak: insights from Shanghai's experience in China. *Risk Manag Healthc Policy.* (2020) 13:3259. doi: 10.2147/RMHP.S283447
62. Ling C, Wen X. Community grid management is an important measure to contain the spread of novel coronavirus pneumonia (COVID-19). *Epidemiol Infect.* (2020) 148:e167. doi: 10.1017/S0950268820001739
63. Tallarek M, Bozorgmehr K, Spallek J. Towards inclusionary and diversity-sensitive public health: the consequences of exclusionary othering in public health using the example of COVID-19 management in German reception centres and asylum camps. *BMJ Glob Health.* (2020) 5:e003789. doi: 10.1136/bmjgh-2020-003789
64. Wang EA, Riley C, Wood G, Greene A, Horton N, Williams M, et al. Building community resilience to prevent and mitigate community impact of gun violence: conceptual framework and intervention design. *BMJ Open.* (2020) 10:e040277. doi: 10.1136/bmjopen-2020-040277

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

frontiers in Public Health

REVIEW
published: 10 March 2022
doi: 10.3389/fpubh.2022.811858

A Survey of Location-Allocation of Points of Dispensing During Public Health Emergencies

Nusaybah Alghanmi[1], Reem Alotaibi[1], Sultanah Alshammari[2], Areej Alhothali[2], Omaimah Bamasag[2] and Kamil Faisal[3]*

[1] Department of Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia, [2] Department of Computer Science, King Abdulaziz University, Jeddah, Saudi Arabia, [3] Department of Geomatics, King Abdulaziz University, Jeddah, Saudi Arabia

Public health emergencies such as disease outbreaks and bioterrorism attacks require immediate response to ensure the safety and well-being of the affected community and prevent the further spread of infection. The standard method to increase the efficiency of mass dispensing during health emergencies is to create emergency points called points of dispensing (PODs). PODs are sites for distributing medical services such as vaccines or drugs to the affected population within a specific time constraint. These PODs need to be sited in optimal locations and have people (demand points) assigned to them simultaneously; this is known as the location-allocation problem. PODs may need to be selected to serve the entire population (full allocation) or different priority or needs groups (partial allocation). Several previous studies have focused on location problems in different application domains, including healthcare. However, some of these studies focused on healthcare facility location problems without specifying location-allocation problems or the exact domain. This study presents a survey of the PODs location-allocation problem during public health emergencies. This survey aims to review and analyse the existing models for PODs location-allocation during public health emergencies based on full and partial demand points allocation. Moreover, it compares existing models based on their key features, strengths, and limitations. The challenges and future research directions for PODs location-allocation models are also discussed. The results of this survey demonstrated a necessity to develop a variety of techniques to analyse, define and meet the demand of particular groups. It also proved essential that models be developed for different countries, including accounting for variations in population size and density. Moreover, the model constraints, such as those relating to time or prioritizing certain groups, need to be considered in the solution. Finally, additional comparative studies are required to clarify which methods or models are adequate based on predefined criteria.

Keywords: points of dispensing, location-allocation, public health emergency, healthcare, disaster response and management

OPEN ACCESS

Edited by:
Eric Carlström,
University of Gothenburg, Sweden

Reviewed by:
Mohammed Sultan,
University of Gothenburg, Sweden
Setsuya Kurahashi,
University of Tsukuba, Japan

****Correspondence:***
Nusaybah Alghanmi
nayyadahalghanmi@stu.kau.edu.sa

Specialty section:
This article was submitted to Disaster and Emergency Medicine, a section of the journal Frontiers in Public Health

Received: *09 November 2021*
Accepted: *31 January 2022*
Published: *10 March 2022*

Citation:
Alghanmi N, Alotaibi R, Alshammari S, Alhothali A, Bamasag O and Faisal K (2022) A Survey of Location-Allocation of Points of Dispensing During Public Health Emergencies. Front. Public Health 10:811858. doi: 10.3389/fpubh.2022.811858

1. INTRODUCTION

Public health emergencies such as disease outbreaks and bioterror attacks demand an immediate response to save people's lives and to prevent the further spread of infection. The Centers for Disease Control and Prevention (CDC) has created a new approach and organizational unit to meet the challenges in responding to bioterror attacks and other large and complex health emergencies,

whether naturally occurring, intended, or casual, such as anthrax attacks (1). Furthermore, being able to respond to a range of future emergencies means that the CDC has to expand its capabilities and responses in terms of scale and speed to cover two global trends: faster and more frequent international travel and the increasing global population (2).

The standard method to increase the efficiency of mass dispensing during health emergencies is to create emergency points, called points of dispensing (PODs) (3). PODs are locations for dispensing medical services, such as vaccines or drugs, to a large number of people, while meeting a specific time constraint (4). PODs are necessary to prevent people who are not sick from becoming infected (5). There are two types of PODs, opened and closed (6). While opened PODs are located at public sites such as schools, closed PODs are operated by a partner organization while the operation continues during the emergency (6).

Poor decision-making while determining the location of healthcare facilities such as PODs results in negative outcomes. These adverse outcomes are not limited to cost and service but also increased infection numbers and deaths due to difficulty in accessing the service (5). A POD need to be sited in a location and, simultaneously, have people assigned to the located facilities; this is known as the location-allocation problem (5). Location-allocation models are used to locate optimal facility locations and allocate demand points to each facility (7). Location-allocation models are operated by planners, who usually determine the number of facilities required (7). The model then locates the facilities before the demand points are allocated to the nearest facility based on a measure such as shortest travel distance or time (7), as shown in **Figure 1**. Facilities may need to selected to serve the the entire population (full demand points allocation) or populations at high risk, or with different priorities or needs (partial demand points allocation).

1.1. Motivation

In March 2020, the World Health Organization (WHO) declared the novel coronavirus disease (COVID-19) a global pandemic (8). During the COVID-19 pandemic, public health authorities required an immediate response plan to access the affected population and ensure they have easy access to the healthcare services and supplies (such as water or food) they need. According to the CDC, distributing food via delivery may be an ideal approach to inhibiting the spread of COVID-19 (9). However, in the case of healthcare services where a physical examination is required, patients need to be able to access physical locations (face to face) to receive services (10).

Given the nature of the fast-spreading of COVID-19, public health authorities across the world needed to respond immediately to ensure the protection of the public, stop the infection from spreading further and provide mass prophylaxis. In the early days of this pandemic, locations needed to be assigned and set up for COVID-19 testing. Then, when COVID-19 vaccines were approved, health facilities and other sites or PODs were needed to provide fair access to the vaccine.

These PODs differ from traditional healthcare facilities, since they involve the provision of easy and fair access for all demand points (5) and have a role in providing medical supplies to protect the public during public health emergencies. However, setting up PODs needs to be done on a large scale and within specific timeframes (4). Thus, locating PODs and allocating the demand points to the designated PODs is a critical and challenging task.

PODs may need to be located to serve the entire population (full allocation) or those who have difficulty accessing PODs and those with different priorities or needs (partial allocation). This survey provides taxonomy-based demand points allocation as full and partial demand points allocation. Which may help improve location-allocation models for efficient PODs assignment while

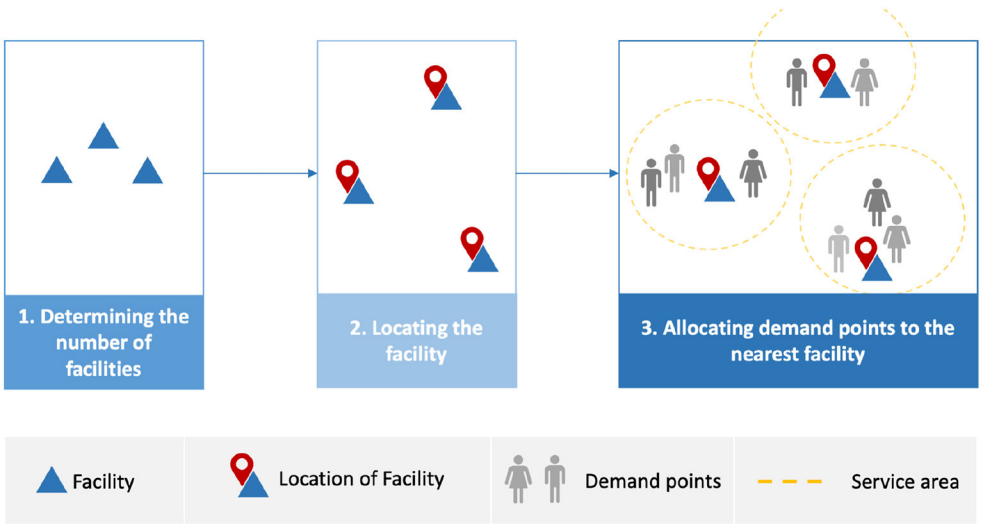


FIGURE 1 | Workflow for location-allocation models.

ensuring fair access for all populations or addressing different populations' needs.

1.2. Contributions

This survey focuses on location-allocation problems for PODs during public health emergencies. Previous surveys have focused on location problems in different application domains, including the location-allocation of general healthcare facilities (11, 12). Location problems "intend to determine the optimum locations for a set of facilities by minimizing or maximizing some objectives for satisfying the existing and/or projected demand with respect to a set of constraints in some given space (11, 13)", while location-allocation problems intend to locate facilities and simultaneously allocate demand points to facilities (5). Surveys, such as Ahmadi-Javid et al. (5) and Afshari and Peng (14), have focused on the locations of healthcare facilities without a focus on the location-allocation problems or specific applications such as PODs during public health emergencies. To the best of our knowledge, there exist no studies surveying PODs location-allocation problems during public health emergencies in the form of allocation decisions (full and partial). Thus, the contributions of this paper are as follows:

- Providing a taxonomy for PODs location-allocation problems during public health emergencies based on demand allocation (full and partial);
- Comparing existing solutions based on their key features, strengths, and limitations;
- Discussing the challenges and issues associated with the current solutions for PODs location-allocation during public health emergencies and providing future directions.

The rest of this survey is structured as follows: Section 2 introduces the background of the components of location-allocation problems, location-allocation models and location-allocation solutions. Section 3 presents survey methodology while, Section 4 presents existing solutions to PODs location-allocation during public health emergencies. Section 5 then discusses the challenges of, and potential future research direction for, location-allocation solutions for PODs during public health emergencies. Finally, Section 6 concludes the study.

2. BACKGROUND

2.1. Components of Location-Allocation Problems

There are three essential components for location-allocation problems: facilities, locations, and customers (15, 16). Facilities reflect various objects with spatial positions to optimize interaction with preexisting objects; an example of a facility is a school or hospital. Locations are a set of candidate points where facilities can be positioned or located. Finally, 'customers' is a general term to indicate any objects interacting with facilities. Customers can be users demanding a service from the facility, for example communities requesting a public service in a rural area. The modeling and analysis of interactions between facilities and customers often require the knowledge of their spatial positions (16). In the remainder, we refer to customers as demand points.

TABLE 1 | List of mathematical notations and input parameters.

Variable	Description
d_{ij}	Travel distance or time from demand point i to the candidate location j.
h_i	Demand at point i.
P	Number of facilities to be located.
f_j	Fixed cost to locate facilities at candidate locations j.
v	Transport costs per unit of demand per distance unit.

TABLE 2 | List of decision variables for PCLPs.

Variable	Description
W	Maximum travel distance from any demand point to its assigned location.
X_j	1 if a facility is located at candidate location j, otherwise 0.
Y_{ij}	1 demand point i is assigned to facility at the candidate location j, otherwise 0.

2.2. Location-Allocation Models

The location problem can be discrete, continuous (5, 17) or network (16, 18). Continuous location problems locate the facility anywhere in a spatial region, while discrete location problems limit facility locations to a set of prespecified candidate points which may include the locations of the demand points (5, 16). Network models implement graph theory to model location problem (16), and for the purpose of composing nodes and links (18). Facilities and demand points can be located only on links or nodes, and any travel between them should be within the network (18).

We focus on the discrete case for several reasons. It is highly flexible in terms of including various economic and geographical features in the models (16). It also provides more natural design results when free land is available and requires locating a new facility at a prespecified place (16). More importantly, using a discrete set of candidate locations is the preferred approach for the majority of location problems and appears frequently in healthcare applications (5). There are two categories of discrete location-allocation problems which are covering-based and median-based problems (5). **Table 1** explains the mathematical notations and input parameters used in their mathematical formulations.

2.2.1. Covering-Based Problems

In covering-based problems, each demand point should be withing a particular distance or time range from the facility that serves them. P-centre location problems (PCLPs) are covering-based problems that aim to minimize the maximum travel distances or times between the selected facilities and the demand points. The decision variables of the PCLPs are presented in **Table 2**, and the formulation is as follows (5, 18):

TABLE 3 | List of decision variables for PMLPs.

Variable	Description
X_j	1 if a facility is located at candidate location j, otherwise 0.
Y_{ij}	1 demand point i is assigned to facility at the candidates locations j, otherwise 0.

TABLE 4 | List of decision variables for FCLPs.

Variable	Description
X_j	1 if a facility is located at candidate location j, otherwise 0.
Y_{ij}	1 demand point i is assigned to facility at the candidates locations j, otherwise 0.

Formulation of PCLPs

$$\min W \tag{1}$$

subject to

$$\sum_j Y_{ij} = 1, \quad \forall i \tag{2}$$

$$\sum_j X_j = P \tag{3}$$

$$\sum_j d_{ij} Y_{ij} \leq W, \quad \forall i \tag{4}$$

$$Y_{ij} \leq X_j, \quad \forall i, j \tag{5}$$

$$Y_{ij} \in \{0, 1\}, \quad \forall i, j \tag{6}$$

$$X_j \in \{0, 1\}, \quad \forall j \tag{7}$$

$$W \geq 0. \tag{8}$$

In the formulations listed above, (1) illustrates the first objective of PCLPs, namely, to minimize the maximum travel time or distance between the demand points and the closest facilities. The constraints are listed from (2) to (8), where (2) requires assigning each demand point to only one facility. Constraint (3) limits the number of established facilities. Constraint (4) states the maximum travel time or distance, which means that W must be greater than the distance between any demand point and its serving facility. Constraint (5) is the facility that should be opened to serve demand points. Finally, constraints (6), (7) and (8) are the domain constraints. Note that (18) considers W a decision variable, while (5) consider it an auxiliary variable.

2.2.2. Median-Based Problems

In this set of location-allocation problems, facilities are located at the candidate locations to minimize the weighted average distance cost among each demand point and the facility to which they are assigned. Median-based problems are divided into p-median location problems (PMLPs) and fixed-charge facility location problems (FCLPs) (5). PMLP aims to locate the facilities while minimizing the weighted travel time or distance. The decision variables of the PMLPs are presented in **Table 3**, and the formulation is as follows (5, 16, 18):

Formulation of PMLPs

$$\min \sum_i \sum_j h_i d_{ij} Y_{ij} \tag{9}$$

subject to

$$\sum_j Y_{ij} = 1, \quad \forall i \tag{10}$$

$$\sum_j X_j = P \tag{11}$$

$$Y_{ij} \leq X_j, \quad \forall i, j \tag{12}$$

$$Y_{ij} \in \{0, 1\}, \quad \forall i, j \tag{13}$$

$$X_j \in \{0, 1\}, \quad \forall j \tag{14}$$

In the formulations listed above, (9) objective of PMLPs minimizing the total demand-weighted travel time or distance between every demand point and their closest facility. The constraints are listed from (10) to (14), where (10) limits the assignment of each demand point to a single facility. Constraint (11) limits the number of established facilities. Constraint (12) requires a facility to be opened in order to serve demand points. Finally, constraints (13) and (14) are integrality constraints.

FCLPs attempt to minimize total costs in terms of traveling and setting up the facilities. The decision variables of the FCLPs are presented in **Table 4**, and the formulation is as follows (5, 18).

Formulation of FCLPs

$$\min \sum_j f_j X_j + v \sum_i \sum_j h_i d_{ij} Y_{ij} \tag{15}$$

subject to

$$\sum_j Y_{ij} = 1, \quad \forall i \tag{16}$$

$$Y_{ij} \leq X_j, \quad \forall i, j \tag{17}$$

$$Y_{ij} \in \{0, 1\}, \quad \forall i, j \tag{18}$$

$$X_j \in \{0, 1\}, \quad \forall j \tag{19}$$

In the formulations listed above, (15) illustrates the objective of FCLPs, namely, to minimize the total cost of demand-weighted distance and facility opening. The constraints are listed from (16) to (19), where (16) requires assigning each demand point to a single facility. Constraint (17) requires opening a facility that serve demand points. Finally, constraints (18) and (19) are integrality constraints.

2.3. Location-Allocation Solutions

There are three solutions approaches for the location-allocation problems (15): Exact solutions, heuristic methods, and metaheuristic methods. Exact solutions (15, 19, 20), such as branch and bound algorithm, find the optimal solution through systematically examining a large subset of all possible feasible combinatorial set of facility location and demand allocation solutions. On the other hand, heuristic methods (15, 19, 20), such as greedy assignment, find the near-optimal solution by examining only a limited subset of the potential combinations. Finally, metaheuristic methods such as genetic algorithm (GA) (15, 21), provide a general framework and a higher-level procedure to design heuristic algorithms which are more powerful than standard heuristic methods.

3. SURVEY METHODOLOGY

This survey focuses on PODs location-allocation during public health emergencies. Thus, two stages were involved in achieving the objectives of the study: examining the results of previous relevant surveys and reviews, and carrying out a literature review. Examining previous surveys helps to understand the topic and identify gaps in survey and review articles. The literature review stage helps find, present and compare research papers proposing a solution for PODs location-allocation during public health emergencies. This stage also analyzes the solution's strengths, limitations and key features to identify particular issues and challenges to guide future directions. This survey focuses on solutions for location-allocation of PODs during public health emergencies; a more detailed explanation and discussion will be presented and provided for these solutions in Section 4.

A hybrid search strategy was adopted using systematic and non-systematic approaches to obtain relevant research papers. In non-systematic approaches, the papers were retrieved through backward and forward citations or snowballing. The databases considered in the search were Web of Science, Scopus, and Science Direct. We also search Google Scholar, a web search engine that indexes a full text or metadata of scholarly literature in almost any area. The existing research papers in PODs location-allocation were retrieved using different keywords, namely location-allocation, points of dispensing, mass vaccination, mass dispensing, emergency medical services. All papers had to be in the field of emergency healthcare. While to find existing survey papers about PODs location-allocation, terms such as survey, review and healthcare facility location were used in addition to the previous search keywords. The title and abstract of each paper were evaluated to consider the relevant papers. The search is limited to papers written in English. A detailed overview of the survey methodology is presented in **Figure 2**.

Most recent and relevant survey and review articles in a range between 2012 and 2021 were examined to obtain an overview of the locations of healthcare facilities or healthcare facility location-allocation in emergency situations. Basar et al. (12) provided a taxonomy for the locations of emergency service stations; the taxonomy covers the type emergency, such as a fire or pandemic disease, as well as use of different objectives, assumptions, constraints, modeling choices, and solutions techniques. Afshari and Peng (14) examined challenges based on the current needs of decision-makers, and methods for locating healthcare facilities to guarantee an optimal solution. They classified literature based on resolved challenges, methods and solutions for facility locations. They also examined the measures used to evaluate the studies in terms of their objective functions and constraints. Ahmadi-Javid et al. (5) presented a paper for both emergency and non-emergency healthcare facility location that included PODs, but presented only three relevant research papers.

Turkoglu and Genevois (11) presented a comparative survey for service facility location problems in different application fields, including healthcare. First, they defined several key features for location problems, such as the number of facilities or objectives. They then defined descriptive dimensions such as application fields, and used these 19 characteristics to present existing solutions. The solutions were categorised based on the application fields and these characteristics were summarized for each field. Moreover, they compared the solutions in different application fields based on these characteristics.

Finally, in the location-allocation problem, Gwalani et al. (22) evaluated and compared four heuristic algorithms to solve the p-median problem in different terms, namely objective function value, time, and stability. Also, they considered the effect of scale (number of sources and destinations) and spatial distribution of destination locations on the performance of these algorithms. Finally, they applied the evaluation in synthetic and real datasets, the latter including resource distribution during bio-emergencies.

4. LOCATION-ALLOCATION MODELS FOR PODS DURING PUBLIC HEALTH EMERGENCIES

This section presents the existing research papers for location-allocation models for PODs during public health emergencies. We focused on retrieving the research papers between 2017 and 2021. As a result, there were (2) and (2) research papers from 2017 and 2018, respectively, while in 2020 and 2021, there are (1) and (4) research papers. The existing location-allocation methods for PODs, as shown in **Figure 3**, are divided based on the allocation of demand points as full demand points allocation and partial demand points allocation.

4.1. Full Demand Points Allocation

Full demand points allocation presents the solutions for locating the facilities regardless of the type of demand points. In other

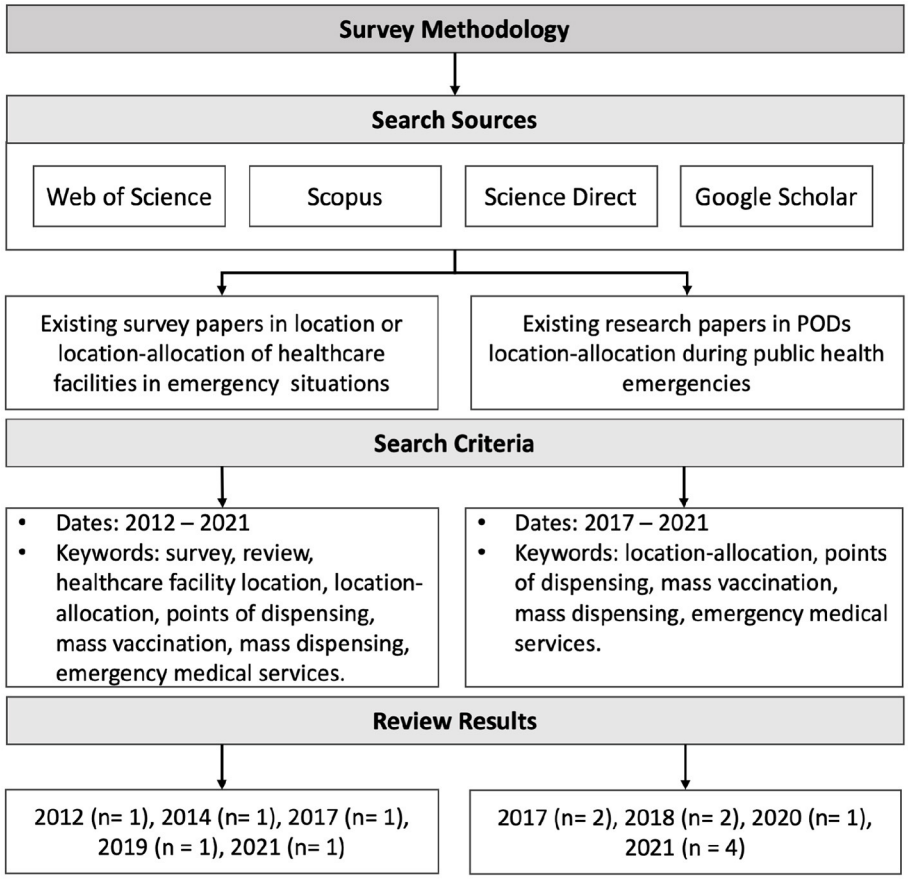


FIGURE 2 | Survey methodology. n refers to number of retrieved papers.

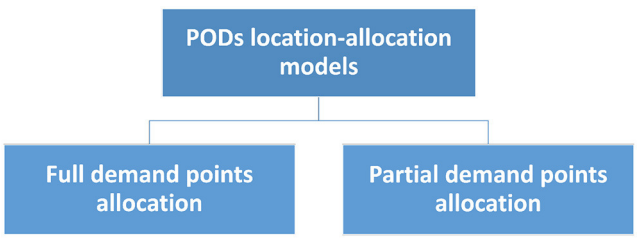


FIGURE 3 | Taxonomy of PODs location-allocation models during public health emergencies.

words, it provides equal access to PODs for all populations, as shown in **Figure 4**. Risanger et al. (23) suggested a model to select testing sites for COVID-19 using pharmacies to overcome the gap in coverage in the US in terms of the number of individuals who wish to perform testing at their nearest site and reduce the distance required to travel. They adopted an optimization model (24), which was used to optimize pharmacy-based distribution of antiviral drugs during the H1N1 pandemic. The objective is to maximize the number of people probably who can travel to limited testing sites (pharmacies). The optimization model is based on mixed-integer linear programming (MILP), they used mathematical optimization such as JuMP or CPLEX to solve it (25, 26), and implementation of solution is freely available via (25). The model used geographic region zip code and data with the population willing to travel as the input (24). The zip codes (mail delivery address) were converted to ZIP Code Tabulation Areas (ZCTAs). ZCTAs are used by the US Census Bureau to help obtain such information as counts, centroid coordinates, and latitudes and longitudes for each ZCTA. The pharmacy datasets were obtained from InfoGroup, Amazon Web Services, and Esri's national COVID-19 database. The results estimated that 94% of the population could access pharmacies, with coverage exceeding 80% and 90% for 47 and 12 states, respectively. However, the capacity of pharmacies is not considered, which may make it difficult to manage matching testing capacity with the testing demand.

In another study, Deng et al. (27) aimed to minimize the number of emergency medical service (EMS) facilities that need to be added to current hospital networks to cover 90% of the population within 15 min of travel time. The population and facility data were obtained from LandScan (28), the Health Bureau of Sichuan Province and the Health Bureau of Chengdu (not available to the public). The proposed

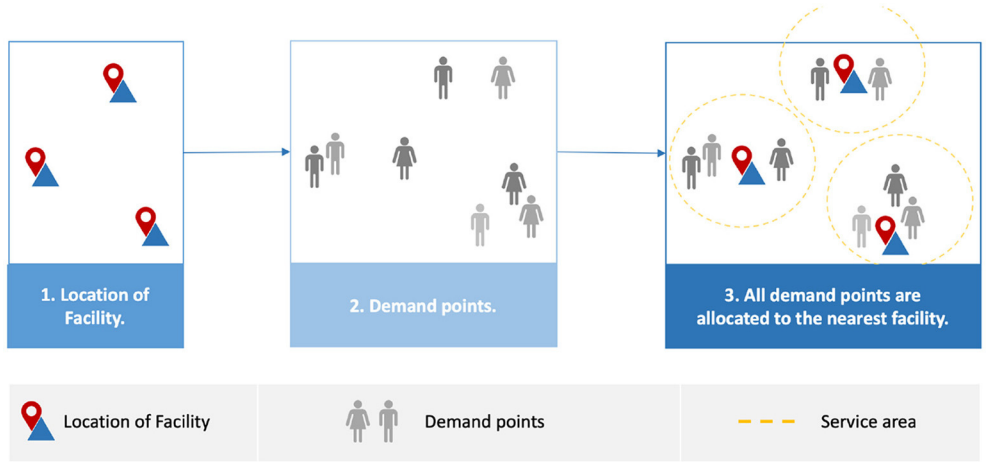


FIGURE 4 | Full demand points allocation.

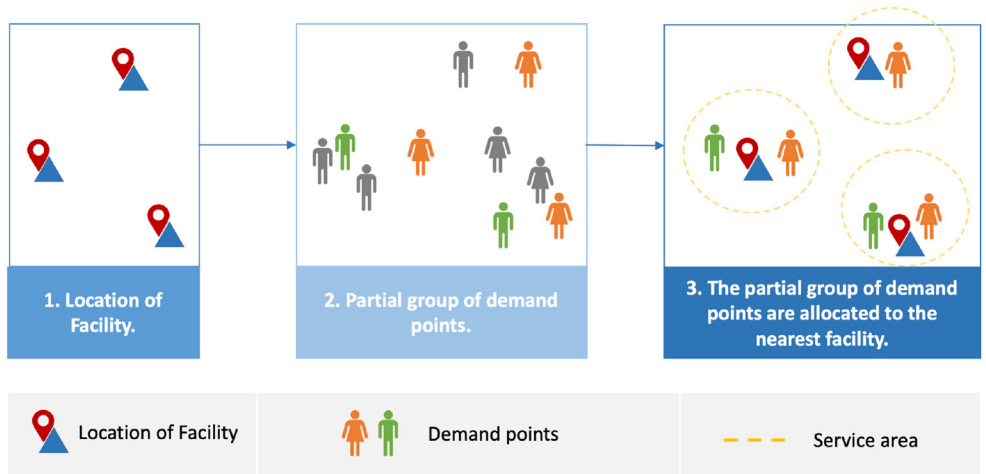


FIGURE 5 | Partial demand points allocation.

solution used Nearest-Neighbor to find the nearest EMS using geographical information systems (GIS), with the shortest one used. To solve the location set covering formulation, a GA was then used. The results demonstrated that 55 of new EMS facilities were able to cover 90% of the population within 15 min. It was also found that to access an EMS facility, the weighted median shortest travel time were reduced by 14.57%. However, in some cases the road network may be affected by traffic jams, leading to an increase in access time.

Devi et al. (29) suggested a model based on MILP for temporary testing laboratories, aiming to minimize the total cost and the travel time from demand points to the laboratories. The overall cost includes fixed, operating, traveling and capacity underutilization costs. They applied the model to Holmberg et al. (30) and found underutilization of capacity. Based on that, they added a third decision variable to capture the capacity needs. The model was applied to a case study in Maharashtra, India, and the data are included in the paper. The results demonstrated that when there are 27 temporary testing laboratories, the total cost for the first objective is 6.08E + 11, while the second objective achieves 30.681 min. However, it would prefer to use ward-village level data to ensure that the centers area located near people.

4.2. Partial Demand Points Allocation

Partial demand points allocation considers a partial group of the population assigned to PODs, as shown in **Figure 5**, for example older people at high risk. Huang et al. (31) proposed a model for allocating four different types of vaccine to priority groups via PODs distribution in Texas in the US. There were five priority groups: ages 0–3, ages 4–24, high risk people aged 25–64, infant caregivers, and pregnant women. The model has three steps, as shown in **Figure 6** (31), which are the primary

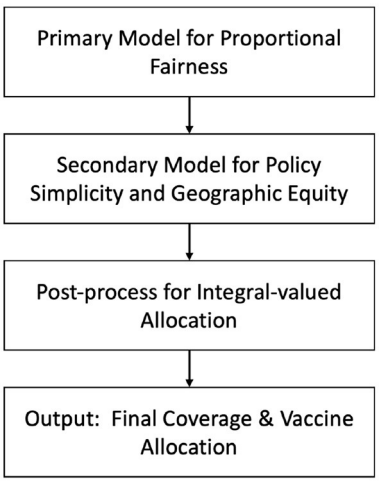


FIGURE 6 | Model for allocating vaccines of multiple types to priority groups at multiple locations (31).

optimization model, secondary optimization model, and post-process. The primary optimization model aims to produce an optimal coverage rate to achieve equal access for each location-priority group pair. The secondary optimization model then reduces the type of vaccine for each priority group and ensures geographic equity by providing similar proportions of vaccine allocation among regions. The final step in the model is the post-processing to obtain integer values for vaccine dose allocations; both primary and secondary optimization model ignores the integrality requirements. The model used priority group data (32) and healthcare locations where the vaccine was available using a tool designed for Texas (33). The results showed that with a small, reserved amount of vaccine (6.8%), the model satisfied the requirement of equal access, with 61.1% coverage of the priority population. However, the number of doses required to achieve immunity may reduce the chance of ensuring fair access for all communities.

Gao et al. (34) proposed two models for the temporary emergency center location-allocation such as M1 and M2. M1 aims to minimize travel time, whereas M2 aims to minimize the rate of mortality risk. Then, GA and modified fuzzy c-means (MFCM) (GA-MFCM) were developed. MFCM was modified to introduce the initial value for mortality risk. Whereas, GA was used to optimize the center of each cluster, and MFCM to group the data. They applied the proposed model in the form of a real dataset from Portland (America) post-earthquake emergencies (34). The results show the M1 model achieves less travel time than the M2 model, and M2 minimizes the total rate of mortality risk for patients. However, the injury severity level at the threshold of death is stated as a deterministic value.

In another study, Hudgeons (35) compared the use of the opened PODs only against using the Home Health Agency (HHA) as closed PODs and examined the impact on maximizing throughput (people's access to PODs) and minimizing resource allocation (staff). The suggested solution consists of replicating the process of services in PODs without HHA and identifying the necessary HHA nurse process. In replicating PODs, RealOpt simulation modeling software was used to show the patient's state traveling to, entering and leaving the PODs. The process of the HHA nurse was then defined as in-home and in-transit activities. For in-home activities, Monte-Carlo simulation was used to estimate the nursing processes required from entering to leaving the patient's home. For the transit modeling, traveling salesman heuristics were used to find the shortest path from the current location to the following location. Data from the nursing faculty at the University of Arkansas (not available to the public), the zip code for the HHA, and the squared area of each zip code (36) were used. The results showed that including the HHA as closed PODs increased throughput by 2.4% and required 16 fewer members of staff. Moreover, the solution targets the vulnerable group but is not based on a real-life case as such it does not specify who was involved and where they were located.

Memari et al. (37) suggested a solution to allocate injured people to temporary emergency stations, with four priorities group from high to low priority. They proposed a new fuzzy dynamic location-allocation with multi-medical servers M/M/c queue model. The model has bi-objectives to minimize the cost to construct temporary emergency stations and death rate and minimize the travel time and queue's response time. Furthermore, a fuzzy number is used to tackle treatment demand, travel time, and arrival treatment rate uncertainty. They used the augmented ε-constraint method to validate the model and a non-dominated sorting genetic algorithm (NSGA-II) to solve the problem; they applied the model in synthetic data and real case from Iran, Tehran (no information about the data). The results demonstrated that the model was able to achieve a good result to find the solutions. However, in some cases the road network may be destroyed due to disaster, leading to need for vehicle routing.

Li et al. (38) suggested a model that could achieve three objectives for locating vaccine sites to provide preventive vaccination to a specific group, in this case children. The three objectives were to minimize average travel distance to demand points, maximize the number of fully open vaccine stations, and minimize total costs, such as the fixed cost of opening the vaccine station or the cost of medical staff. A mixed-integer nonlinear programming (MINLP) model was used, which was divided into two stages to reduce the computational burden. Firstly, minimizing average travel distance is considered the main objective, and this objective and other objectives are solved independently using MILP; secondly, the other two objectives are considered constraints. The model was applied to Nanshan CDC in Shenzhen, China; the data for address and areas of vaccination stations are obtained from CDC. Vaccination stations, demand points and other data are available in (39). The results demonstrated that opening 50 vaccine sites involves a trade-off between three objectives, which helps CDC's decision-making. However, moving the demand point from one location to another may involve the need to re-assign people to a new and closer vaccine station.

Emu et al. (40) suggested the priority in conjunction with distance-based vaccine distribution model (PD-VDM) based on constraint satisfaction programming (CSP) to optimize the

TABLE 5 | Summary of location-allocation solutions for PODs during public health emergencies.

Reference	Methodology	Objective function	Constraints	Decision Variables	Location-allocation model	Case Study	Datasets
Huang et al. (31)	Optimization model	Maximize fair access for different priority groups	Discretionary doses	Regions for health service, vaccine types and priority groups	Coverage-based	Texas, US	Priority groups (32) healthcare places for vaccine (33).
Gao et al. (34)	GA and MFCM	Two-objectives: Minimize travel time Minimize the rate of mortality risk	Constraints: (2) and at least one patient assign to facility	Y_{ij}	Median-based	Portland, US	Population and people geographical coordinates locations (34).
Hudgeons (35)	RealOpt simulation modeling, Monte-Carlo simulation and traveling salesman heuristics	Maximize throughput and minimize resource allocation	Maximum waiting time, required utilization per PODs, and number of workers (41)	Number of workers in each POD (41)	Coverage-based	-	Data from nursing faculty (not available to the public), zip code for HHA, and the squared area of each zip code (36).
Memari et al. (37)	NSGA-II, M/M/c	Bi-objectives: minimize the cost to construct emergency stations and death rate and to minimize the travel time and queue's response time	Total patient demands in a temporary station at time t, number candidate locations, patient allocates to the nearest and only one site, number of medical servers, waiting time, idle probabilities, cost of constructing a temporary station	A patient assigns to a temporary station at time t, a selected temporary station at time t, list of selected temporary stations at time t, number of temporary stations are selected from candidate locations, number of medical servers at time t in a temporary station	Coverage-based	Tehran, Iran	Simulated data source (37).
Risanger et al. (23)	Facility location optimization model	Maximize coverage for people want to perform the test	Constraints: (2), (3), (5), (6), (7)	Candidate locations and the nearest locations for predefined areas	Coverage-based	US	Areas, pharmacies (23) and Population willing to travel (24).
Deng et al. (27)	Nearest-Neighbor and GA	Minimize number of new facilities	Percentage coverage	Candidate locations and the demand points are covered by candidate locations within 15 min	Coverage-based	Chengdu, China	Population data LandScan (28). Road network from National Geomatics Center of China. Supply side such as healthcare facilities from Health Bureau of Sichuan Province and the Health Bureau of Chengdu.
Li et al. (38)	MINLP model	Multi-objectives: minimize average travel distance for demand points, maximize the	open facility, fixed cost of opining facility and labor	Demands group, medical staff, fully opening facility, opening facility, workdays of	Median-based	Shenzhen, China	The address and areas of vaccination stations are obtained from CDC. Vaccination stations, demand points and

(Continued)

TABLE 5 | Continued

Reference	Methodology	Objective function	Constraints	Decision Variables	Location-allocation model	Case Study	Datasets
		Number of fully open vaccine stations, and minimize the total costs	cost	opening facility and order amount for each facility	Median-based	Shenzhen, China	other data are available in (39).
Emu et al. (40)	K-medoid and CSP	Maximize vaccine distribution for priority groups and minimize the average travel distance	One employee vaccinates one person, each person receives one vaccine from a single employee and the availability of the vaccine	The DC allocates an employee for the person to be vaccinated	Median-based and coverage-based	Chennai, India	Hospital locations distance from google map and age distribution during census 2011 (40).
Devi et al. (29)	MILP model	Bi-objectives: Minimize the cost and the travel time	Constraints: (2), (4), (5), fairness of access, number of facilities	X_j, Y_{ij} and the capacity of facility	Coverage-based	Maharashtra, India	Holmberg et al. (30) and real data (29).

vaccine distribution, aiming to maximize distribution for priority groups. In this case, they considered age and minimized average travel distance for individuals to get vaccinated. The PD-VDM model is initialized by using k-medoid to select the number of distribution centers (DCs) and then the priority groups are assigned by minimizing the average distance. They performed two experiments based on the randomly generated data and real data obtained from Chennai, India. Additionally, they compared their model with other models using different factors, such as none or one of the distance and priority factors. They found that, their proposed model (using randomly generated datasets) was able to vaccinate the highest priority groups at 100% while reducing the average travel distance by more than 40%. However, in the real case, the model could vaccinate less than 90% of the three highest priority groups while reducing the average travel distance by more than 70%, which made the proposed model better than others. However, number of doses required to achieve immunity may reduce the chance of fair access for all communities and other groups needs.

Table 5 summarizes current work on location-allocation for PODs during public health emergencies in terms of reference, methodology, objective function, constraints, decision variables, type of the location-allocation model, datasets, and case study region (when applicable). The methodology is the solution for the proposed model. The objective function of the numerical value that could be maximized or minimized (42). Constraints are defined as the variable's possible values, while decision variables are the set of values that need to be defined to solve the problem (42). The location-allocation model is as described in Section 2.2. Datasets refer to the data used in the proposed model, while case study refers to whether the model is applied to a specific location, such as a particular city.

Table 6 presents a comparison of current work on location-allocation for PODs based on their advantages and limitations during public health emergencies. **Table 7** compares studies based on a range of key features: locating facilities, identifying number of facilities, the number of new facilities, type of facility, density, and full or partial demand points allocation. In terms of locating facilities, the physical locations for PODs are selected, while the identifying number of facilities defines the number of PODs needed to accomplish the desired objective. Meanwhile, the number of new facilities identifies the number of new PODs needed in addition to the current set of facilities to accomplish the desired objective. The type of facility defines the place allocated to provide the service, such as a pharmacy. Finally, in terms of density, it is stated if the proposed solution covers different population densities.

5. CHALLENGES AND FUTURE RESEARCH DIRECTIONS

Section 4 presented different solutions currently proposed for the location-allocation of PODs during public health emergencies. However, certain issues and limitations remain that must be addressed in future studies. This section discusses these challenges and suggests future research directions for PODs location-allocation during public health emergencies.

- **Analysis of demand points**

  Demand for services in PODs will vary from country to country and from one kind of emergency event to another. For example, the COVID-19 vaccine is not appropriate for children, which may change the allocation decision. Existing solutions either assume that specific groups (38) are involved,

TABLE 6 | A comparison of location-allocation solutions for PODs during public health emergencies based on their advantages and limitations.

Reference	Advantages	Limitations
Huang et al. (31)	- Allocating the different types of vaccine (four types) for priority groups via PODs distribution in Texas, US.	- The number of doses required to achieve immunity may reduce the chance of fair access for all communities.
Gao et al. (34)	- Two objectives are considered as M1 and M2: M1 aims to minimize travel time, while M2 aims to minimize the rate of mortality risk.	- The injury severity level at the threshold of death is given as a deterministic value.
Hudgeons (35)	- Using closed PODs instead of only using opened PODs. - Including closed PODs with opened PODs increases throughput by 2.4% and decreased staff shortage by 16 persons.	- The solution targets the vulnerable group but is not based on a real-life case as such it does not specify who was involved and where they were located.
Memari et al. (37)	- Tackling treatment demand, travel time, and arrival treatment rate uncertainty.	- In some cases the road network may be destroyed due to disaster, necessitating vehicle routing.
Risanger et al. (23)	- Selecting testing sites for COVID-19 using pharmacies to overcome gaps in coverage in the US. - 94% of the population could access pharmacies.	- The capacity of pharmacies is not considered, which may make it difficult to manage matching testing capacity with the testing demand.
Deng et al. (27)	- Minimizing the number of EMS facilities that need to be added to current hospital networks. - 55 of new EMS facilities are able to cover 90% of the population within 15 min of travel time.	- In some cases the road network may be affected by traffic jams, leading to an increase in access time.
Li et al. (38)	- Locating vaccine sites whilst minimizing average travel distance for demand points, maximizing the number of fully open vaccine stations, and minimizing total costs. - Opening 50 vaccine sites makes a trade-off among three objectives, which helps CDC decision-making.	- Moving the demand point from one location to another may involve the need to re-assign people to a new and closer vaccine station.
Emu et al. (40)	- Maximizing vaccine distribution for priority groups and minimizing the average travel distance.	- The number of doses required to achieve immunity may reduce the chance of fair access for all communities and other groups needs.
Devi et al. (29)	- Providing solution for temporary testing laboratories with aiming to minimize the cost and the travel time from demand points to the laboratories.	- It would prefer to use ward-village level data to ensure that the centers area located near people.

TABLE 7 | A comparison of location-allocation solutions for PODs during public health emergencies based on their key features.

Reference	Locating facilities	Identifying number of facilities	Number of new facilities	Type of a facility	Density	Full demand points allocation	Partial demand points allocations
Huang et al. (31)	-	-	-	-	-	-	✓
Gao et al. (34)	✓	-	-	-	-	-	✓
Hudgeons (35)	-	-	-	HHA	-	-	✓
Memari et al. (37)	✓	-	-	-	-	-	✓
Risanger et al. (23)	✓	-	-	Pharmacy	✓	✓	-
Deng et al. (27)	✓	-	✓	-	-	✓	-
Li et al. (38)	✓	✓	-	-	-	-	✓
Emu et al. (40)	✓	✓	-	-	-	-	✓
Devi et al. (29)	✓	-	-	-	-	✓	-

or select them based on priorities in a specific type of emergency event (31).

Thus, any analysis of the desired group (such as a priority or a vulnerable group) is very challenging and needs more attention due to the varied types of emergency (such as a pandemic or tsunami) and the needs of different groups of people (for example the elderly, children, or pregnant women). More importantly, the point or location of demands needs to be considered, along with whether it is easy to access the PODs or a new POD needs to be set up.

- **Covering different countries and population**

Population size and density differ from one country to another; current solutions focus either on China (27, 38) or the US (23, 31). A few cases from other countries such as Iran and India (37, 40). A wider variety of solutions is needed to cover populations of different sizes

and densities in other countries and cities in addition to China or the US. Doing so may help decision-makers to locate and utilize PODs according to the country's needs and to allocate them to populations of different sizes and densities.

- **Model constraints**

  PODs are locations for dispensing medical services, such as vaccines or drugs, to a large number of people while meeting a specific time constraint (4). As shown in **Table 5**, PODs location-allocation problem considers variety constraints such as budget or number of the fully open facility.

  Therefore, PODs location-allocation problem needs to consider other types of constraints related to PODs location-allocation problems, such as solving the problem with the required timeframe to ensure the coverage of either entire population or partial population. Also, the partial group such as vulnerable or priority groups can be considered a constraint for the model.

- **Evaluation and comparative studies**

  To address the location-allocation problem, Gwalani et al. (22) evaluated and compared four heuristic algorithms to resolve the p-median problem as applied to different terminologies, namely objective function value, time, and stability. However, there is a dearth of comparative studies evaluating methods utilizing several criteria, involving determining which methods are most applicable to maximize population coverage for populations of different sizes and densities. This will be a very interesting research direction for researchers seeking to provide data to evaluate and compare models and methods efficiently.

6. CONCLUSION

Public health emergencies such as disease outbreaks need PODs to dispense medical services such as vaccines to a large number of people within a specific period of time. PODs need to be situated in an optimal location and have demand points assigned to them simultaneously; this is known as the location-allocation problem. PODs may need to be selected to serve the entire population (full allocation) or different priority or needs groups (partial allocation). This paper presents a survey of PODs location-allocation models during public health emergencies and provides a taxonomy according to full and partial demand points allocation, and discusses a range of studies that have employed this taxonomy, comparing the advantages, limitations and key features of each one.

The survey concluded that in order to improve PODs location-allocation models during public health emergencies, there is a need to develop various techniques to analyze and define the demand of partial groups and provide the desired coverage to those demand points. Efforts to propose models to cover the needs of different countries, including variation in population size and density, are urgently needed. Furthermore, model constraints, such as time or priority groups need to be considered in the solution. Moreover, additional comparative studies are required to clarify which methods or models are adequate based on predefined criteria. Finally, this work has discussed the current challenges associated with existing techniques and recommended future research areas in PODs location-allocation models.

AUTHOR CONTRIBUTIONS

NA, RA, and SA: conceptualization and methodology. NA: formal analysis, investigation, writing—original draft preparation, and visualization. NA, RA, SA, AA, OB, and KF: resources, writing—review and editing, and funding acquisition. RA and SA: supervision. SA: project administration. All authors have read and agreed to the published version of the manuscript.

FUNDING

The authors extend their appreciation to the Deputyship for Research & Innovation, Ministry of Education in Saudi Arabia for funding this research work through the project number IFPRC-055-612-2020 and King Abdulaziz University, DSR, Jeddah, Saudi Arabia.

ACKNOWLEDGMENTS

The authors thank Drs. Harsha Gwalani and Alper E. Murat for their useful comments and discussions.

REFERENCES

1. Redd SC, Frieden TR. CDC's evolving approach to emergency response. *Health Security*. (2017) 15:41–52. doi: 10.1089/hs.2017.0006
2. Saker L, Lee K, Cannito B, Gilmore A, Campbell-Lendrum DH, et al. Globalization and infectious diseases: A Review of the linkages. Geneva: World Health Organization (2004).
3. Buck BH, Cowan L, Smith L, Duncan E, Bazemore J, Schwind JS. Effective practices and recommendations for drive-through clinic points of dispensing: a systematic review. *Disaster Med Public Health Preparedness*. (2020) 15:374–88. doi: 10.1017/dmp.2020.15
4. Capitol Region Council of Governments C. *Point of Dispensing Staff Orientation*. (2017). Available online at: https://crcog.org/wp-content/uploads/2017/12/POD-Staff-Orientation.pdf (accessed August 6, 2021).
5. Ahmadi-Javid A, Seyedi P, Syam SS. A survey of healthcare facility location. *Comput Operat Res*. (2017) 79:223–63. doi: 10.1016/j.cor.2016.05.018
6. for Disease Control C, Prevention. *Fact Sheet: Medical Countermeasures (MCM) and Points of Dispensing (POD) Basics*. (2019). Available online

at: https://www.cdc.gov/cpr/readiness/healthcare/documents/MCM_Dispensing_Factsheets_03_MCM.pdf (accessed on May 22, 2021).
7. Tomintz M, Clarke G, Alfadhli N. Location-allocation models. In: Brunsdon C, Singleton A, editors. *Geocomputation: A Practical Primer*. London: Sage (2015). p. 185–98.
8. Archived: WHO Timeline-COVID-19. *World Health Organization*. (2020). Available online at: https://www.who.int/news/item/27-04-2020-who-timeline--COVID-19 (accessed on May 18, 2021).
9. for Disease Control C, Prevention. Considerations *for Food Pantries and Food Distribution Sites*. (2021). Available online at: https://www.cdc.gov/coronavirus/2019-ncov/community/organizations/food-pantries.html (accessed on January 7, 2022).
10. of Health AGD. *Providing Health Care Face to Face During COVID-19*. (2020). Available online at: https://www.health.gov.au/health-alerts/COVID-19/coronavirus-COVID-19-advice-for-the-health-and-disability-sector/providing-health-care-face-to-face-during-COVID-19 (accessed on January 7, 2022).
11. Turkoglu DC, Genevois ME. A comparative survey of service facility location problems. *Ann Operat Res*. (2019) 292:399–468. doi: 10.1007/s10479-019-03385-x
12. Başar A, Çatay B, Ünlüyurt T. A taxonomy for emergency service station location problem. *Optimizat Lett*. (2012) 6:1147–60. doi: 10.1007/s11590-011-0376-1
13. Hale TS, Moberg CR. Location science research: a review. *Ann Operat Res*. (2003) 123:21–35. doi: 10.1023/A:1026110926707
14. Afshari H, Peng Q. Challenges and solutions for location of healthcare facilities. *Ind Eng Manage*. (2014) 3:1–12. doi: 10.4172/2169-0316.1000127
15. Azarmand Z, Neishabouri E. Location allocation problem. In: *Facility Location*. Heidelberg: Physica-Verlag HD (2009). p. 93–109.
16. Scaparra MP, Scutella MG. *Facilities, Locations, Customers: Building Blocks of Location Models. A Survey*. Pisa: Università di Pisa (2001).
17. Eiselt HA, Marianov V. *Foundations of Location Analysis. Vol. 155*. New York, NY: Springer Science & Business Media (2011).
18. Daskin MS. *Network and discrete Location: Models, Algorithms, and Applications*. New York, NY: John Wiley & Sons (1995).
19. Cooper L. Location-allocation problems. *Operat Res*. (1963) 11:331–43. doi: 10.1287/opre.11.3.331
20. Bennett WD. A location-allocation approach to health care facility location: a study of the undoctored population in Lansing, Michigan. *Soc Sci Med D Med Geography*. (1981) 15:305–12. doi: 10.1016/0160-8002(81)90006-X
21. Mladenovic N, Brimberg J, Hansen P, Moreno-Pérez JA. The p-median problem: a survey of metaheuristic approaches. *Eur J Operat Res*. (2007) 179:927–39. doi: 10.1016/j.ejor.2005.05.034
22. Gwalani H, Tiwari C, Mikler AR. Evaluation of heuristics for the p-median problem: scale and spatial demand distribution. *Comput Environ Urban Syst*. (2021) 88:101656. doi: 10.1016/j.compenvurbsys.2021.101656
23. Risanger S, Singh B, Morton D, Meyers LA. Selecting pharmacies for COVID-19 testing to ensure access. *Health Care Manage Sci*. (2020) 24:330–8. doi: 10.1101/2020.09.17.20185090
24. Singh B, Huang HC, Morton DP, Johnson GP, Gutfraind A, Galvani AP, et al. Optimizing distribution of pandemic influenza antiviral drugs. *Emerg Infect Dis*. (2015) 21:251. doi: 10.3201/eid2102.141024
25. Risanger S, Singh B, Morton D, Meyers LA. *Selecting pharmacies for COVID testing*. (2020). Available online at: https://github.com/srisanger/selecting-pharmacies-for-COVID-testing (accessed on January 4, 2022).
26. Singh B, Huang HC, Morton DP, Johnson GP, Gutfraind A, Galvani AP, et al. *Appendix 1: Optimizing Distribution of Pandemic Influenza Antiviral Drugs*. (2020). Available online at: http://www.bio.utexas.edu/research/meyers/_docs/publications/SinghEID14Supplement.pdf (accessed January 4, 2022).
27. Deng Y, Zhang Y, Pan J. Optimization for locating emergency medical service facilities: a case study for health planning from China. *Risk Manage Healthcare Policy*. (2021) 14:1791. doi: 10.2147/RMHP.S304475
28. Bhaduri B, Bright E, Coleman P, Urban ML. LandScan USA: a high-resolution geospatial and temporal modeling approach for population distribution and dynamics. *GeoJournal*. (2007) 69:103–17. doi: 10.1007/s10708-007-9105-9
29. Devi Y, Patra S, Singh SP. A location-allocation model for influenza pandemic outbreaks: a case study in India. *Operat Manage Res*. (2021) 24:1–16. doi: 10.1007/s12063-021-00216-w
30. Holmberg K, Rönnqvist M, Yuan D. An exact algorithm for the capacitated facility location problems with single sourcing. *Eur J Operat Res*. (1999) 113:544–59. doi: 10.1016/S0377-2217(98)00008-3
31. Huang HC, Singh B, Morton DP, Johnson GP, Clements B, Meyers LA. Equalizing access to pandemic influenza vaccines through optimal allocation to public health distribution points. *PLoS ONE*. (2017) 08;12:e0182720. doi: 10.1371/journal.pone.0182720
32. Huang HC, Singh B, Morton D, Johnson G, Clements B, Meyers L. *S2 Appendix: Priority Group Population Estimation*. (2017). (accessed on May 18, 2021).
33. TACC TACC. *Texas Pandemic Flu Toolkit; 2013-2020*. Available online at: http://flu.tacc.utexas.edu (accessed May 18, 2021).
34. Gao X, Zhou Y, Amir MIH, Rosyidah FA, Lee GM. A hybrid genetic algorithm for multi-emergency medical service center location-allocation problem in disaster response. *Int J Ind Eng*. (2017) 24. doi: 10.23055/ijietap.2017.24.6.4299
35. Hudgeons A. *Dispensing Medical Countermeasures in Public Health Emergencies via Home Health Agencies and Points of Distribution*. (Industrial Engineering Undergraduate Honors Theses) (2018).
36. ProximityOne. *Census 2010 ZIP Code Demographic Profile Dataset*. (2010). Available online at: http://proximityone.com/cen2010_zcta_dp.htm (accessed May 30, 2021).
37. Memari P, Tavakkoli-Moghaddam R, Partovi M, Zabihian A. Fuzzy dynamic location-allocation problem with temporary multi-medical centers in disaster management. *IFAC PapersOnLine*. (2018) 51:1554–60. doi: 10.1016/j.ifacol.2018.08.275
38. Li X, Pan Y, Jiang S, Huang Q, Chen Z, Zhang M, et al. Locate vaccination stations considering travel distance, operational cost, and work schedule. *Omega*. (2021) 101:102236. doi: 10.1016/j.omega.2020.102236
39. Pan Y, Huang Q, Shiqiang J, Li X, Chen Z. *Data for: Locate Vaccination Stations With Travel Distance, Operational Costs and Work Schedule Considered*. (2020). Available online at: https://data.mendeley.com/datasets/8jmkwc45tt/1 (accessed on May 26, 2021).
40. Emu M, Chandrasekaran D, Mago V, Choudhury S. Validating optimal COVID-19 vaccine distribution models. In: *International Conference on Computational Science*. Cham: Springer (2021). p. 352–66.
41. Lee EK, Chen CH, Pietz F, Benecke B. Modeling and optimizing the public-health infrastructure for emergency response. *Interfaces*. (2009) 39:476–90. doi: 10.1287/inte.1090.0463
42. McDill ME. *Chapter 11: Basic Linear Programming Conceptsg*. (2000). Available online at: https://www.courses.psu.edu/for/for466w_mem14/PDFs/Ch11_LPIntro.PDF (accessed on May 18, 2021).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 15 March 2022
doi: 10.3389/fpubh.2022.841013

Impacts and Lessons Learned of the First Three COVID-19 Waves on Cross-Border Collaboration in the Field of Emergency Medical Services and Interhospital Transports in the Euregio-Meuse-Rhine: A Qualitative Review of Expert Opinions

Anja Sommer[1,2*†], *Cassandra Rehbock*[1,2*†], *Clara Vos*[1], *Christina Borgs*[1], *Sabrina Chevalier*[3], *Simone Doreleijers*[2], *Marie Gontariuk*[2], *Sofie Hennau*[4], *Eva Pilot*[2], *Hanna Schröder*[1,5], *Loth Van der Auwermeulen*[4], *Alexandre Ghuysen*[3,6], *Stefan K. Beckers*[1,5] *and Thomas Krafft*[2]

[1] Aachen Institute for Rescue Management and Public Safety (ARS), University Hospital RWTH Aachen, Aachen, Germany, [2] Department of Health, Ethics and Society, Faculty of Health, Medicine and Life Sciences, Care and Public Health Research Institute (CAPHRI), Maastricht University, Maastricht, Netherlands, [3] Public Health Department, Faculty of Medicine, University of Liege, Liège, Belgium, [4] Center for Government and Law, Faculty of Law, Hasselt University, Hasselt, Belgium, [5] Department of Anaesthesiology, Medical Faculty RWTH Aachen, University Hospital RWTH Aachen, Aachen, Germany, [6] Emergency Department, Liège University Hospital Centre, Liège, Belgium

Background: In the Euregio-Meuse-Rhine (EMR), cross-border collaboration is essential for resource-saving and needs-based patient care within the emergency medical service (EMS) systems and interhospital transport (IHT). However, at the onset of the novel coronavirus SARS-COV-2 (COVID-19) pandemic, differing national measures highlighted the fragmentation within the European Union (EU) in its various approaches to combating the pandemic. To assess the consequences of the pandemic in the EMR border area, the aim of this study was to analyze the effects and "lessons learned" regarding cross-border collaboration in EMS and IHT.

Method: A qualitative study with 22 semi-structured interviews was carried out. Experts from across the EMR area, including the City of Aachen, the City region of Aachen, the District of Heinsberg (Germany), South Limburg (The Netherlands), and the Province of Limburg, as well as Liège (Belgium), took part. The interviews were coded and analyzed according to changes in cross-border collaboration before and during the pandemic, as well as lessons learned and recommendations.

Results: Each EU member country within the EMR area, addressed the pandemic individually with national measures. Cross-border collaboration between regional actors was hardly or not at all addressed at the national level during political decision- or policymaking. Previous direct communication at the personal level was replaced by national procedures, which made regular cross-border collaboration significantly more difficult. The cross-border transfer regulations of patients with COVID-19 proved to be

OPEN ACCESS

Edited by:
Jarle Løwe Sørensen, University of South-Eastern Norway, Norway

Reviewed by:
Amir Khorram-Manesh, University of Gothenburg, Sweden
Dagan Schwartz, Ben-Gurion University of the Negev, Israel

***Correspondence:**
Anja Sommer
ansommer@ukaachen.de
Cassandra Rehbock
crehbock@ukaachen.de

†These authors have contributed equally to this work and share first authorship

Specialty section:
This article was submitted to Disaster and Emergency Medicine, a section of the journal Frontiers in Public Health

Received: *21 December 2021*
Accepted: *27 January 2022*
Published: *15 March 2022*

Citation:
Sommer A, Rehbock C, Vos C, Borgs C, Chevalier S, Doreleijers S, Gontariuk M, Hennau S, Pilot E, Schröder H, Van der Auwermeulen L, Ghuysen A, Beckers SK and Krafft T (2022) Impacts and Lessons Learned of the First Three COVID-19 Waves on Cross-Border Collaboration in the Field of Emergency Medical Services and Interhospital Transports in the Euregio-Meuse-Rhine: A Qualitative Review of Expert Opinions. Front. Public Health 10:841013. doi: 10.3389/fpubh.2022.841013

complex and led, among other things, to patients being transported to hospitals far outside the border region. Collaboration continues to be seen as valuable and Euregional emergency services including hospitals work well together, albeit to different degrees. The information and data exchange should, however, be more transparent to use resources more efficiently.

Conclusion: Effective Euregional collaboration of emergency services is imperative for public safety in a multi-border region with strong economic, cultural, and social cross-border links. Our findings indicate that existing (pre-pandemic) structures which included regular meetings of senior managerial staff in the region and a number of thematic working groups were helpful to deal with and to compensate for the disruptions during the crisis. Regional cross-border agreements that are currently based on mutual but more or less informal arrangements need to be formalized and better promoted and recognized also at the national and EU level to increase resilience. The continuous determination of synergies and good and best practices are further approaches to support cross-border collaboration especially in preparation for future crises.

Keywords: cross-border, emergency medical service (EMS), interhospital transport, Euregio Meuse-Rhine, collaboration, crisis management, cooperation, EU cross-border mechanism

INTRODUCTION

Crises, such as natural disasters or disease outbreaks, increase the strain on healthcare services including the emergency medical services (EMS). System preparedness, based on its readiness and adaptability, is vital to provide an adequate level of care to people in need (1). This includes the provision of high-quality care and transport of patients to the nearest and most appropriate hospital. To achieve short ambulance response times, a key factor for patient survival, inter-sectoral and cross-border collaboration are crucial (2, 3).

The novel coronavirus SARS-COV-2 (COVID-19), which reached the European Union (EU) in early 2020, had a significant and rapid impact on inter alia healthcare (1). The fragmentation of the EU in their approaches to tackling the pandemic became apparent and showed the need for public health reforms at the regional, national, and European levels (4, 5).

More specifically, the virus challenged cross-border collaboration regarding EMS. Particularly in regions such as the Euregio-Meuse-Rhine (EMR), which comprises the Southern tip of The Netherlands (South Limburg), the larger Aachen region in Germany, and North-Eastern Belgium (covering the German-speaking community and parts of the French and Flemish-speaking communities), cross-border cooperation is essential to provide appropriate patient care with the appropriate resources, including elective and emergency healthcare (6, 7). Before the COVID-19 pandemic, more than 160,000 people per year crossed the border of Belgium, The Netherlands, Germany, Luxembourg, or France to receive medical care during emergencies or elective treatments (8). Due to the EMR's characteristics, based on its geography, laws, languages, cultures, and economies, Euregional agreements, such as in healthcare, ease the collaboration between the relevant national actors. EMS and hospitals in the region are dependent on a well-functioning cross-border collaboration, though national borders remain an obstacle in the continuous development of the EMR (9–11).

With the increased spread of COVID-19, the cooperation between EU countries changed and general European benefits such as free movement {art. 3.2 Treaty on European Union (TEU) and art. 21.1 [Treaty on the functioning of the European Union (TFEU)]} were hindered if not prohibited (12–15). Cooperation can rely on general legal instruments regarding cross-border cooperation. In the European context, the Madrid Outline Convention (16) and the European grouping of territorial cooperation (EGTC) Regulation (17) are leading instruments. With respect to cross-border healthcare, the Directive 2011/24/EU of the European Parliament and of the Council of March 9, 2011 on the application of patients' rights in cross-border healthcare also serves as a basis for cross-border cooperation (art. 168.2 TFEU) (12, 18). Nonetheless, European Member States acted independently and sometimes reinstated border controls, which impacted cross-border healthcare provisions negatively (14).

As the pandemic progressed in different waves, not every country was affected at the same time and at the same level. **Figure 1** demonstrates the timeline based on the differing official dates of the first three COVID-19 waves (until March 2021) in The Netherlands, Germany, and Belgium.

This study aims to assess the impacts and consequences of the first three COVID-19 waves on cross-border collaboration between regional actors regarding prehospital care in the EMR. In doing so, we hereby distinguish between primary and secondary ambulance missions. Primary missions are emergency rescue missions including the patient transfer from the emergency scene to the next suitable hospital, where an initial stabilization and first

Abbreviations: EMR, Euregio Meuse-Rhine; EMS, Emergency Medical Service(s); IHT, Interhospital transport(s); MICU, Mobile Intensive Care Unit.

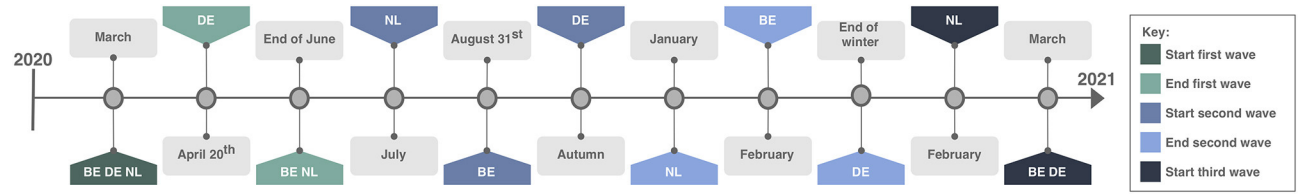


FIGURE 1 | COVID-19 waves reported in Belgium, Germany, and the Netherlands (further detail on hospital surge capacity planning can be found in the **Supplementary Figure 1**) (19–24).

or definite treatment can occur (25). Secondary patient transports or interhospital transports (IHT) include all patient transfers from primary healthcare facilities to a secondary or tertiary care hospital in rural areas. They are frequently necessary to provide comprehensive patient care (26), based on reasons ranging from inadequate bed capacity to a lack of a tertiary department or special equipment (27).

Investigating the impacts of and lessons learned from the pandemic on cross-border collaboration regarding EMS and IHT, we focused on: changes in cross-border collaboration before and during the pandemic, as well as lessons learned and recommendations.

This research adds a relevant and detailed analysis to some previous studies (6, 7, 9). Based on the experiences and insights of Euregional practitioners and experts in the field of EMS and IHT during the first three COVID-19 waves, this study underlines the importance of collaboration in this particular cross-border setting under these demanding circumstances.

METHODS

We conducted semi-structured interviews with experts and practitioners based in the EMR and from various fields, such as the hospital, dispatch center, and ambulance/firefighting service, to explore the impacts and consequences of the COVID-19 pandemic. The study was approved by the ethics committee of the medical faculty of RWTH Aachen, Germany (registration numbers: EK 390/20, CTC-A 20-417). All participants signed an informed consent form.

Defining Collaboration Within the EMR Setting

For this study, we follow van Houtum's "cross-border cooperation approach" [(28), p. 73]. The focus here lies on interacting in a beneficial/useful manner based on mutual understanding. The key terms are "effectiveness, success, tools, instruments, connectivity, openness, (dis)similarities, differences, synergy, networks, cooperation, and alliances" [(28), p. 73]. The EU Directive on the application of patient's rights in cross-border healthcare similarly aims to enable cross-border healthcare safely and with high quality by promoting cooperation among the EU Member States [(3), Ch. 2, p. 35]. In the EMR, close cooperation is needed due to the shared regional challenges and opportunities defined by the geographical specifics, as well as economic and financial settings and interdependencies (10, 11). For our study, we particularly analyzed the EMR in regard to a cooperation between the several German, Dutch, and Belgian municipalities, counties, and health districts bundled together in this cross-border area. This overarching cooperation is subsequently strengthened by underlying collaborations.

We define cross-border collaboration in this study as "an activity or arrangement in the field of healthcare undertaken by two or more cooperating actors, located in different systems/countries, with the aims of transferring or exchanging patients, providers, products, services, funding, or healthcare knowledge across the border which separates them" [(3), Ch. 7, p. 219]. In the EMR, cross-border collaboration has evolved during the last decades as a long-lasting relationship among the relevant key stakeholders in public safety, and especially, in the field of EMS and IHT, collaboration is exercised as a daily routine (10, 11).

To facilitate collaboration on public safety within the EMR a group of key stakeholders [Euregio Meuse-Rhine In Geval Van Crisis/In Case of Crisis (EMRIC)] has been formed more than two decades ago. It brings together (public) organizations in firefighting, EMS, and civil protection from either side of the borders with the aim to support, coordinate, and intensify the collaboration among emergency services, health authorities, hospitals, and fire services in this border region. EMRIC is not a legal entity but organizes the Euregional cooperation of the operational structures in thematic working groups consisting of representatives of, for example, the local EMS (29, 30). From this group, the idea of the International Knowledge and Information Centre in public safety (IKIC) project was initiated and this study is a part of the project (31).

The studied region includes the Belgian provinces Liège (incl. German-speaking Community) and Limburg, the Dutch province South-Limburg, and the German city of Aachen, City Region Aachen, and District of Heinsberg in North-Rhine Westphalia (NRW). As the research area covers The Netherlands, Germany, and Belgium, the international abbreviations NL, DE, and BE are used in the results depending on the readability.

Figure 2 gives an overview of all medical cross-border missions in the above-mentioned research area. Overall, a total of 1,147 medical cross-border missions (EMS and IHT) were reported in 2019, of which 715 (62,3%) had the destination NL, 321 (28,0%) the destination DE, and 111 (9,7%) the destination BE. Compared to this, a total of 976 medical cross-border missions were reported in 2020, of which 532 (54,5%) to NL, 371 (38,0%) to Germany, and 73 (7,5%) to Belgium. Particularly in

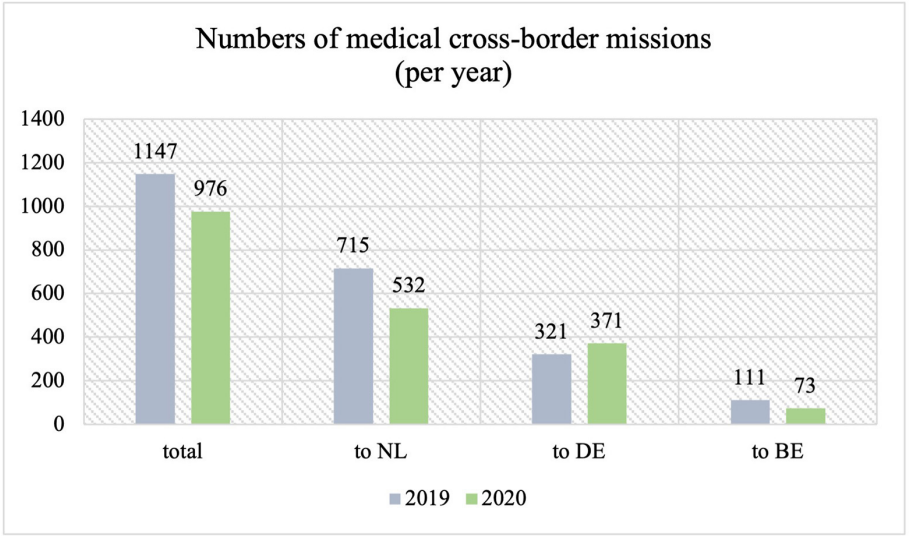


FIGURE 2 | Emergency medical service (EMS) cross-border missions and interhospital transports (IHT) in 2019 and 2020 in the research area.

these cases, DE consists of the cities/regions Düren, Euskirchen, District of Heinsberg, City Region Aachen, and City of Aachen, NL of South-Limburg, and BE of Liège and Hasselt (comprising the whole EMR area). This data was provided by the Fire Department of the City of Aachen as part of EMRIC. Further data can be found in the **Supplementary Material**.

EMS Systems in the EMR

The EMS systems in Germany, the Netherlands, and Belgium, and thus also in the EMR, differ regarding their structures, operational standards and procedures, as well as their respective underlying tasks. For life-threatening emergencies, the German and Belgian emergency responses usually include emergency physician units (DE: NEF; BE: SMUR/MUG) in addition to ambulances with paramedics, whereas the Dutch system is based on paramedics only, but with considerably higher qualifications compared to the German and Belgian paramedics. Response time requirements differ, as well as the triage systems that are used by the respective emergency dispatch centers. Also, the availability of resources and the threshold (criticality) that must be reached to qualify for a medical response from the EMS system differ quite significantly, with the Dutch system having comparatively fewer resources and thus higher thresholds because of the requirements set by the Dutch government. While all these differences continue to coexist in the EMR, pragmatic and effective answers have to be found in the daily working routine when one of the dispatch centers in the region is requesting the dispatch of EMS resources across the border to allow for the fastest qualified response available to a critical emergency (2, 32–34).

Data Collection

Overall, a total of 22 interviews were conducted according to a semi-structured interview guide (see **Supplementary Material**). The guide covered topics related to pre-existing cross-border agreements in the field of EMS and IHT, experiences of participants during the first three COVID-19 waves, the impact of COVID-19 measures on the Euregional collaboration, lessons learned, and recommendations for the future collaboration in the EMR. The interviews were conducted either in German, Dutch, French, or English by 5 interviewers of the study team.

Participants of the study included experts at the political and crisis management level, medical directors (EMS), dispatch center managers, physicians, as well as firefighting, and EMS practitioners from various collaborating institutions and organizations in the EMR (**Table 1**), allowing for a wide scope of unique viewpoints on the studied topics during the initial crisis.

Participants were invited from January to June 2021. The interviewees were actively involved in the management of the COVID-19 pandemic; therefore their availability was very limited, resulting in an extension of the recruitment period and lower participant numbers in certain regions (for example, The Netherlands) than initially anticipated.

ID numbers (ID 1-22) were used to refer to the participants' statements (**Table 2**). Each number represents one expert.

Data Analysis

All interviews were transcribed verbatim (excluding sounds), anonymized, and translated into English by the interviewers and native speakers (except for the German interviews). Afterward, all interviews were analyzed in English or German. The software Atlas.ti Web 9 (ATLAS.ti Scientific Software Development GmbH, Berlin) was used to facilitate the collaborative coding process. This allowed joint discussions on the coding processes of each individual interview among the research group, in which the native interviewers were also partaking.

Thematic coding based on the interviews was applied (35). The coding book was carefully revised and adapted based on discussions of emerging results, allowing for a detailed overview of relevant findings. Predominant themes of the initial interview

TABLE 1 | Details of the study participants ($N = 22$).

		Stadt Aachen, DE	StädteRegion Aachen, DE	Kreis Heinsberg, DE	Limburg, BE	Province Liège, BE	Zuid-Limburg, NL
Participants	Medical director EMS	1		1	1[a]		1
(function/expertise)**	Hospital/emergency physician	1	1		2	2	2
	Political level/crisis management*	1				1	1
	Ambulance/firefighting service*	1				2	
	Manager dispatch center				1	1	1
	Dispatch center*			1			

[a] *The participant was also a parliamentary advisor.*
**representative; **most participants fulfilled several roles but were only interviewed as for ex. manager of the dispatch center.*

TABLE 2 | Participant IDs per country.

Germany (DE)	ID 1–7
The Netherlands (NL)	ID 8–12
Belgium (BE)	ID 13–22

guide (see **Supplementary Material**) were used to structure the results according to the following sections: the collaboration before and during the pandemic, as well as the lessons learned and recommendations. To increase readability, the findings were additionally divided among the topics EMS and IHT with regard to any involved operational processes.

RESULTS

In total, 22 experts in the fields of EMS and IHT in the EMR were interviewed, 7 from Germany, 5 from The Netherlands, and 10 from Belgium. The experts were asked about their experiences of cross-border collaboration before the COVID-19 pandemic, changes during the pandemic, and missed opportunities in the cross-border collaboration in EMS and IHT, as well as recommendations for future collaboration within the EMR.

Cross-Border Collaboration Before the COVID-19 Pandemic

Cross-Border Collaboration in General (EMS and IHT)

The cross-border collaboration in the EMR (also through EMRIC) prior to the pandemic is perceived as well-functioning and based on solid foundations (ID 1, 4, 6, 11, 16). Several respondents refer to various general agreements concerning cross-border collaboration that are in place, in addition to more specific agreements around fire protection, EMS or disaster management (ID 4, 5, 8, 9, 11). Further agreements between municipalities exist in certain border regions. These agreements take effect when one's own regional resources cannot reach a certain area in the legal time frame and can be reached faster by foreign units (ID 9). At the operational level, the overall collaboration in EMS and IHT is perceived as functional (ID 1, 6, 16).

Cross-border collaboration by means of the emergency helicopter "Christoph Europa 1" (stationed in Würselen, DE), is perceived as very well-functioning (ID 8, 18). The German helicopter conducts a lot of missions in Dutch Limburg (ID 8) and regularly supports EMS in the province of Liège (BE) (ID 18). The responsible parties of the Dutch Netwerk Acute Zorg Limburg (NAZL; Network acute care Limburg) and Christoph Europa 1 meet twice a year to exchange information and discuss any difficulties (ID 8).

While the cross-border collaboration with South-Limburg has been successful for many years and communication across the border appears to be relatively easy and direct between the services, the collaboration with Limburg North occurs infrequently and is viewed to be more complex (ID 8, 9).

There is less collaboration between BE and both NL and DE (ID 11, 18), although NL does request BE resources occasionally (ID 13). Possible reasons for less support requested by BE from the neighboring countries include better spatial coverage by their own ambulance resources close to its borders with NL and DE, differences in EMS structures, and a language barrier for the French-speaking part (ID 11). Overall, BE receives more help than it provides to DE or NL (ID 18). One expert emphasizes that in cross-border collaboration, there is never an equal balance between the countries, meaning that there is always one predominantly receiving and another one requesting resources (ID 13).

EMS Operational Processes

In the last years, no specific problems were reported when requesting or providing help in the cross-border setting (ID 1, 6, 16). German ambulances are usually obliged to transport patients to the nearest suitable hospital, also during a cross-border mission (ID 3). Still, in the border region, German EMS teams try to bring German patients to German hospitals and Dutch patients to Dutch hospitals, even if the hospital from the respective neighboring country is closer (ID 5, 6). One German expert emphasized that Dutch hospitals admit every patient transported by German ambulances to the emergency room (ID 3). On occasion, Dutch and Belgian ambulances also bring patients to DE if this is the nearest intensive care unit (ICU) bed available (ID 2). Cross-border care is challenging for BE as it is uncommon, and processes seem to be unknown

among participants (ID 18, 19). The usual procedure in BE is to seek permission from their dispatch center to approach a hospital outside of their own region (ID 16, 18, 21). Belgian ambulances are only allowed to bring patients across the border if an emergency physician is on-scene and the foreign hospital has the specialized department required to treat the patient (ID 16, 19, 21). Between certain medical specialization departments and NL hospitals, (informal) agreements were established with the BE EMS service, including for example agreements on pediatric emergency patients, which can be transported directly to the hospital in Maastricht without requesting prior permission from the dispatch center (ID 21). One participant mentioned that the transport of German-speaking Belgians to a German hospital can be challenging because of the underlying structures (ID 18). The following illustrates a specific scenario where an exception was made regardless of the usual processes; several patients from a mass casualty event in BE (a terrorist attack on Place Saint-Lambert in Liège) were transported by Dutch ambulances to Maastricht (NL), whereas patients would usually be transported interprovincially (ID 18).

German experts feel that speaking German during a patient handover or when communicating with the Dutch dispatch center in The Netherlands is very beneficial (ID 1, 7).

> *"[…] If a patient [...] because he is Dutch or Belgian, or because I have the mission in The Netherlands or Belgium, want to transport him to a hospital there, I have never personally encountered problems. It always worked great to place the patient there, yes, one does not exactly know who needs to be called, because that has changed several times especially in Maastricht, now. But still you were always welcomed in a friendly manner and from my point of view it works much more smoothly than here in Germany" (ID 1).*

Concerning the acceptance and recognition of educational background and competencies, each country accepts those of the foreign EMS staff, and everyone works according to their own standards and standard operating procedures (SOPs) for treatment (ID 5, 11, 20). Related to this, two BE experts are under the impression that the different levels in acute care training and the differences in performing medical procedures by the various urgent care teams are problematic (ID 14, 15). One Belgian expert also describes the differences among the EMS vehicles as a challenge, as regular emergency physician vehicles do not exist in NL, neither the Paramedical Intervention Team (PIT) (higher qualified staff compared to regular ambulances in BE) in DE and NL, and because Belgian ambulances are not legally recognized in DE (ID 17).

In general, handover procedures are carried out according to the guidelines of the country to which the patient was transported (ID 20). In the District of Heinsberg, a cross-border handover protocol (DE and NL) is in place, which was developed by an EMRIC working group and helps to give a structured overview about the most important handover facts in Dutch and German:

> *"[…] The EMS expects how to hand over the patient now, as quickly as possible, as it is in Germany. And in The Netherlands they have such expectations, what's next, and do they announce it to me correctly, do they make a sensible handover for me?! And I think this structured protocol has contributed to this [...] because it is then relatively clear, okay, they will want to know that from me soon. And so that you have it available, that's why it's [stored] on the vehicles, then we take [...] and fill it out or browse through it when it comes to the registration" (ID 6).*

In EMS, the pre-announcement en-route to the receiving hospital is done by calling the destination hospital directly (independently of where the hospital is located) (ID 1, 9, 10, 21):

> *"So I try to call the hospital directly with the numbers I have, so that it doesn't have to go through the dispatch center from Aachen to Maastricht from Maastricht to the hospital' I'm actually lucky that someone always speaks German [...]" (ID 1).*

This facilitates that the emergency department staff is adequately prepared for the arrival of a new patient; pre-announcement is especially expected from Dutch hospital staff (ID 10).

IHT Operational Processes

Cross-border IHT between NL and DE are regularly performed, while everyone concentrates on their own processes, no difficulties are perceived (ID 1, 2, 7):

> *"The Dutch hardly ever transport interhospital to Germany. They have a functioning, adequate health system with a [...] much better-appearing organizational structure in terms of intensive care transport from hospital to hospital [...]. Belgium also has a well-functioning health system, which is of course oriented towards Liège and Brussels. [...] Our contact region is East Belgium with the German-speaking area, which by law is fundamentally entitled […] to be treated by someone who speaks German" (ID 2).*

Cross-border IHT from BE to DE or NL is possible (ID 16, 20), although the transport between hospitals is not considered to be emergency medical care in Belgium but is rather classified as non-urgent patient transport (ID 20) and is usually only coordinated within certain provincial networks nearby (ID 18). In addition, cross-border IHT from Belgium are only allowed in certain circumstances under certain conditions (ID 15, 18) and the BE system favors transferring patients within the same province or to the next Belgian province (ID 18). If a child in critical condition needs intensive care and nearby Belgian hospitals with a pediatric ICU are not available, one expert reports very positive experiences in referring children to the hospital in Maastricht (ID 19). For pediatrics and neonatology, certain agreements exist between hospitals in BE and NL (ID 21). This is in line with the (informal) agreements for EMS to transport children directly to Maastricht (ID 21). The expert was impressed by the level of care *via* the mobile intensive care unit (MICU) retrieval teams from Maastricht as shown in the past (ID 19).

Requests for patient takeovers and IHT from NL or BE to DE are particularly very rare (ID 2):

> *"Interhospital transfers from The Netherlands [are] an absolute exception. And if that's 3 in the year, it's a lot" (ID 2).*

Nonetheless, a strong collaboration between the hospitals in Aachen and Maastricht exists (ID 8). When performed, cross-border IHT generally operate the same way as within their own country; a transport request is made and if a bed is available at a certain hospital, the IHT will take place (ID 9, 11). In addition, IHT between the hospitals in Eupen (BE) and Aachen take place and are organized informally, without involving the dispatch centers (ID 13).

A collaboration between the MICU in Maastricht and the MICU in the Region of Aachen is in place but is rarely used (ID 1). IHT in NL provided by a German MICU usually does not happen (ID 3). Only if the Dutch MICU is not available or does not have the capacity to perform a certain IHT, a German ambulance or MICU is requested to pick up the patient in The Netherlands or the other way around (ID 3, 5).

Operational Dispatching Processes (EMS and IHT)

Communication among dispatch centers in the EMR is unproblematic and straightforward according to one NL expert (ID 8). The responsibility for EMS missions lies with the country where the incident happened, however, if a cellphone call is wrongly directed to one dispatch center due to the proximity to the border, the call needs to be referred to the responsible dispatch center (ID 5):

> *"[...] a classic example would be that in Vaals [...] there is an emergency, and the Dutch then contact us to ask whether the ambulance station 7 [in Aachen] is manned by an ambulance and if that is the case, it will then be dispatched to Vaals, [...] but remains a mission in the responsibility of the Dutch. [...] If that is an emergency request by mobile phone from Vaals, it then arrives at the dispatch center [in Aachen] and they now see ok, we also have the ambulance 7 available, then, of course, they could say, we will send it to you directly because that is also actually possible according to our German regulations [..]. But we are not allowed [...] we forward this emergency call to Maastricht, [...] they make the decision whether they want the corresponding support from Aachen or not" (ID 5).*

Similarly, for IHT cases, the responsibility lies with the dispatch center in the region where the patient is picked up (ID 5). Consequently, patients can be transferred over the border without the need to inform all involved parties (ID 5). For example, a transport provided by NL from a Dutch to a German hospital only involves contact and information exchange between the Dutch hospital, the Dutch dispatch center, and the German hospital. The German dispatch center is not informed or involved, and the contact between hospitals is usually by telephone (ID 6). Generally, in the region of Heinsberg, it is perceived that the Dutch dispatch center calls more often for help from the German dispatch center than vice versa. However, a special vehicle for infant transportation is sometimes requested from the dispatch center in Maastricht as it is the closest special-purpose vehicle in the area around Heinsberg and Aachen (ID 7).

In NL, the regulations and guidelines for the quality parameters of EMS systems are described to be different compared to DE regulations. One example is that the required time to arrive at the scene is monitored much stricter in NL and can influence their decision-making to request help from neighboring EMS:

> *"[...] for the Dutch, it is very important how for example the time of arrival is and when the German vehicles [arrive]. So [...] they alert a German ambulance, then they have to be able to understand exactly how long this ambulance has now required [to arrive at the scene]" (ID 5).*

To reach their target of a 15-min arrival time to very critical patients (urgency level A1 in NL), the dispatch center in Maastricht regularly requests ambulances from DE due to their closer proximity to certain areas such as Vaals (NL) (ID 11). The Dutch EMS can only fulfill the time limit of 15 min in more than 95% of the A1 (highest urgency) rides with support from the German EMS (ID 11). On the contrary, the Dutch EMS are well-placed to cover the border-region to Belgium with their own resources and consequently require less support from Belgium. In BE, DE or NL ambulances may only be requested if they can reach the emergency scene at least 10 min before their own BE resources (ID 13).

When it comes to a request for help, the Dutch dispatch center, for example, calls the German dispatch center to share the most important information and the relevant emergency keyword. However, the German dispatcher decides which emergency keyword will be chosen to alert the German EMS resources. The decision to dispatch a certain urgency level or EMS response may differ from the original request because the Dutch and German emergency keywords and processes are different (ID 7):

> *"[...] I have a heart attack on this and that address [...][it is] the same as what we ask. But in the end, we have to think about it ourselves, does that fit our [...] emergency keyword or not? If we now have a heart attack, [we] will just send an ambulance plus physician there, regardless of whether they [originally only asked] for an ambulance" (ID 7).*

Cross-Border Collaboration During the COVID-19 Pandemic

At the beginning of the pandemic, the collaboration proceeded at the same level for non-COVID-19 patients. On the contrary, for patients with COVID-19, cross-border collaboration was only possible *via* personal and informal agreements between stakeholders. Over the course of the pandemic, cross-border missions and transfers decreased in cases of non-COVID-19 patients and patients with COVID-19 were only transferred across the border after introducing official coordination measures at the national level (ID 2, 3, 4, 5, 8, 9, 10, 12, 13, 17, 20).

Respondents consider the collaboration between NL and DE before and during the pandemic to be particularly good since it is based on already existing partnerships (ID 5, 8, 11).

Cross-Border EMS Missions During the Pandemic (Non-COVID-19 Patients)

Some experts assumed that cross-border missions still took place in the same quantity as before the pandemic (ID 1, 10), while others felt that cross-border interaction decreased especially with

Belgium (ID 3, 16). Decreasing numbers of cross-border cases between Aachen and BE and between NL and BE have also been experienced before COVID-19 (ID 3, 11). After the initial phase of the pandemic, the number of cross-border missions returned to the same level between Heinsberg and NL (ID 6).

Cross-Border IHT Missions During the Pandemic (COVID-19 Patients) Before the Implementation of National Planning Tools

Because Germany has more ICU capacity than Belgium and The Netherlands, requests for taking over patients with COVID-19 over the course of the pandemic were mainly directed toward Germany (ID 13, 10, 21).

Cross-border IHT collaboration between NL and DE was more common in the first peak of the pandemic when insufficient ICU beds were available in Limburg (NL) and patients were transferred to Germany (ID 8, 9); this was based on the existing relationships between Maastricht, Aachen, and Venlo, but also between Enschede, Twente (NL), and the corresponding German hospitals (ID 8). The communication and initiation of this IHT happened at the hospital level (ID 9).

The number of patients who were transferred to German hospitals decreased as the pandemic proceeded. Patients were mainly transported to other Dutch hospitals, especially when regions were labeled as high incidence areas (ID 4).

> *"So the Dutch first and foremost allocate within the country before they go abroad, which is actually not the normal situation. The normal situation near the border is actually [...] that one also exchanges across borders. Amidst high incidence, that doesn't happen currently" (ID 4).*

For BE, cross-border IHTs were stopped and BE did not accept foreign patients during the first two waves. Anything that fell within the EMS agreements (outside of COVID-19) continued and the general rules were followed. Patients with COVID-19 were not transported abroad, and neither were any accepted at the beginning (ID 20), except for specific cases (ID 13, 21), which were transported abroad by the Belgian military (ID 21).

During the second wave and only if national resources were not available, BE patients were brought across the border, outside of the Belgian hospital network (ID 13, 20). The province of Liège was impacted significantly by the pandemic and around 230 patients had to be transferred (which accounts for their entire provincial ICU capacity) (ID 13, 17, 18). Of these 230 patients, 30 patients were transferred to DE (ID 13). Also, patients could be transported, who under normal circumstances would not have been allowed to be transferred due to the national guidelines (ID 14). Normal cross-border EMS cases, excluding COVID-19 cases, continued during the pandemic as regulated by the official national agreement between NL and BE (ID 20). In addition, extraordinary agreements for patients with COVID-19 were implemented at the national level which led to the take-over of Dutch and French patients in BE Limburg and the transfer of Belgian patients to Germany. These IHT did not create any obstacles (ID 20), even though there were a few concerns and cross-border IHT were closely monitored by a sub-team in BE that organized the cross-border transfers (ID 13). In rare cases, German ambulances or MICU picked BE patients up in Belgium and transferred them to Germany. German ambulances often also transferred Belgian patients back to BE; this was also the case for Belgium, which sent out resources to pick up patients in Germany and transferred them back home (ID 13). This allowed for flexibility in cross-border IHT and created more resource capacity in BE (also for non-emergency transports) (ID 13). Patients were only transferred back to Belgium if they were no longer in need of ICU treatment and received their final treatment in BE hospitals (ID 18). Other patients, however, completed their hospitalization in the foreign hospitals across the border and at times deceased there (ID 18). One Belgian expert explained that BE hospitals selected which patients were viable for cross-border transport very carefully. This seemed to be well-appreciated by receiving hospitals since patients did not arrive in unstable critical conditions (ID 18).

EMS and IHT Operational Processes

With the onset of the pandemic, Belgian hospitals (mainly Verviers or St. Vith) directly asked the university hospital in Aachen to take over ICU patients; this was coordinated as per usual *via* telephone between the physicians (ID 2, 16). One expert stated that the tele-EMS physician in Aachen played an essential role in pre-announcing cross-border ICU patients at the respective hospitals for IHT (ID 4).

At a political level, Germany agreed to take over BE patients when BE reached its capacity limit (ID 16). When certain missions were officially initiated at a political level, cross-border IHT with national resources took place but Belgian patients were also transported by German ambulances while billing issues remained unclear (ID 4). One expert explained how help is always provided first, and legal questions need to be discussed afterward (ID 9):

> *"If another dispatch center calls for support, we will arrange the support and whether or not this is allowed, we will see afterward. [...] it's all about the patient's health in the first place and the rest will follow" (ID 9).*

The process of IHT between the hospitals in Eupen and Aachen changed during the pandemic and was organized formally *via* the dispatch center in Liège (ID 13).

Organizing transfers from BE to DE was very challenging and time-consuming and the coordinating team had to be able to speak French/German or French/English (ID 13). Already existing contacts through EMRIC and the medical working group cross-border emergency medical assistance in the EMR (EUMED) facilitated the transfer of BE patients to the close border region around Aachen in Germany (ID 13).

IHT processes included the ongoing contact among the DE and NL EMS and the director of the trauma center in Maastricht. Neither side considered it necessary to change previous habits and operational processes, including differences in personal protective equipment (PPE) or hygienic measures (ID 3, 9, 11). National, regional, and local standards and measures were recognized by the other countries just as before the pandemic (ID 9, 11).

"No, we actually asked [the responsible persons from the Dutch EMS and from the Maastricht University Hospital] [...] whether we come into conflict with our somewhat different PPE concept [...] and they said: 'You do as you want, and we do as we want. And we also accept your scheme as you want, so everything is not a problem'" (ID 3).

The national treatment guidelines of patient care in the cross-border setting could still be applied by the EMS teams as before the pandemic:

"Overall, as far as I know, the cross-border collaboration continued to function just as it did before. And the Dutch came over to us for missions and [...] treated a COVID-19 patient according to the Dutch system and we did the same [...] in The Netherlands or Belgium" (ID 5).

Resource Capacity and Management During the Pandemic

Resource requests from the dispatch center in Maastricht to the district of Heinsberg (which was hit seriously during the onset of the pandemic) decreased significantly. The dispatch center in Heinsberg was also not always able to provide help when asked for resources, as its own resources were very scarce (ID 7).

Capacity problems in the initial phase of the pandemic in hospitals on both sides (NL and DE) led to hardly any patients being accepted from across the border. For example, only Dutch patients or patients living in the border region could be brought to a Dutch hospital, but otherwise, foreign patients were not accepted in NL (ID 7) and neither in BE (ID 20). German patients from Heinsberg were therefore often not transported to Dutch hospitals when resources were scarce on both sides of the border (ID 7):

"And then they said, [...]'we're full, right, go to your hospitals'; we hardly asked then because it was difficult to explain to the German there that he was going to be driven to Holland, where the incidences are perhaps even higher. [...] then, of course, they didn't really want that either" (ID 7).

Admitting patients with COVID-19 to an ICU implies long-term hospitalization and ICU treatment. Hence, tying up considerable resources for a long time for one patient needs to be considered when agreeing to accept foreign patients (ID 2, 18).

Information Exchange During the Pandemic

A Euregional dashboard facilitated the exchange of essential information (ID 4, 14). One main challenge, however, was the different approaches to processing certain information, like differing working and decision-making processes based on different factors. For example, in Germany, decision-making was based on incidence numbers (ID 4).

Crisis management team discussions in the City and City Region of Aachen included data of EMS resources and bed capacity planning of hospitals in the EMR (including COVID-19 patient numbers and bed capacities, which are updated daily on the NL and DE side) (ID 1, 11). This data was also shared with BE (ID 14). Other than that, cross-border cooperation was not discussed any further (ID 1, 11). Additionally, another expert from a different region was not aware of cross-border topics being discussed in the crisis management teams (ID 10).

Close communication between actors across the borders (federal police Germany, EMR, EMRIC, other crisis management teams) remained intact (ID 4, 5, 20), but no contact person from NL or BE was actively involved in the local crisis management teams in Germany (ID 4,5).

Experts working operationally experienced that at a political level, cross-border support was promised very quickly and seen as having worked very well-despite the fact that detailed information of cross-border rescue missions (who brings a patient from Belgium to Germany for example) was not properly exchanged and the execution was left to the operational EMS teams (ID 1, 2). Additionally, it was difficult to give definite numbers to foreign countries on how many patients could be received, as hospitals had to make sure they were available for patients in their own region (ID 2).

"[...] There was this appeal from Belgium to take on patients. [...] so it happened one evening that a patient was supposed to be transferred from Eupen, who was completely stable [...] and for whom a primary physician vehicle had to [be dispatched] [...] and that was [a] totally useless waste of resources and then you only get told from the upper level that this is a highly political matter, we have to do that now, and I just think that's wrong, [...] if you already have a crisis management team, and if you have such a big situation, then [...] you can't personally boast about: 'I always have an emergency physician for you [...]' [...] But thank God that only happened once" (ID 1).

"In the end, you need a setting where it is clear [that] when [...] two governments at federal or state level say that this is now [the] concept: Patients are transferred from country A to country B - [...] it cannot be that the discussion starts [again] via the micro-management [level] with the respective manager or dispatcher from the EMS [. . .], about which vehicle is going where and whether it can drive with a special signal and how many people... can join there and if a patient is [transported], who will pick him up and whether the Belgian EMS will have to do that [...]and who informs him" (ID 2).

One expert, at a higher managerial level in the EMS, had an opposing viewpoint and could not report any difficulty at the operational level (ID 5):

"So in the [...] operational business [...] nothing became known [to me] that there were difficulties [...] somewhere" (ID 5).

This was supported by one German expert at the crisis management level who concluded that much more intensive cross-border communication and exchange took place (ID 4). Also, new Euregional working groups were created within EMRIC, forming a new European project named PANDEMRIC (ID 4).

No problems were reported to the experts regarding border closings; these had no operational impact for EMS or IHT (ID 5, 7, 8, 9, 16, 17, 20). One expert explained that the fear of border controls led to an arrangement where BE ambulances were being

escorted by police forces to avoid any transfer problems at the borders (ID 14).

The Implementation of New National Planning Tools During the Pandemic (COVID-19 Patients)

All three countries eventually implemented changes to the national organization of IHT, especially for patients with COVID-19 during the pandemic.

In NL, IHT had to be managed according to national guidelines and through the regional [Regionaal Coördinatiecentrum Patiënten Spreiding (RCPS)] and national coordination center [Landelijk Coördinatiecentrum Patiënten Spreiding (LCPS)] for both the national and international IHT. This was a major obstacle to the cross-border collaboration between NL and DE as this made Euregional or direct communication and transfers impossible (ID 5, 8, 10, 11).

> *"So the only thing I found unfortunate, especially when the LCPS really came onto the scene, that they were very much attached to the national borders" (ID 10).*

International transports in Belgium were organized by the central government, for which a national task force was established: the Surge Capacity and Transport Taskforce (ID 17, 20). In contrast to before, these transports were now organized *via* the dispatch center in Liège (ID 17). One expert criticized information from the task force as being insufficient, as hospitals and EMS were not informed properly about capacity in other regions (also across the border within the EMR) (ID 21).

A new coordination point in Münster (Germany) was introduced focusing specifically on the coordination of cross-border IHT in Germany (ID 2, 9). This center is responsible for the allocation of ICU resources. Some experts explained that the center did not coordinate cross-border IHT but was rather a point of contact (ID 2).

> *"The state government and the federal government provided regulation for Covid treatment within the framework of this cluster regulation, [...] a communication center [...] attached to the university hospital in Münster, which primarily [...] should take over the locating of intensive care resources. [...] That was well thought out on paper. In reality, it was the case that the staff in Münster took calls and then said [...] 'call the nearest hospital and talk to them' [...], then we had to refer them to Münster and then the hospital in Münster said to the dispatch center 'yes, but you have already called Aachen, then call again'. And when we said 'we had no capacity', he would call Münster again and say 'Aachen says they have no capacity', and then maybe the colleagues in Münster suggested a second hospital, where he then had to call as well" (ID 2).*

The coordination point redirected any call for help to, for example, the Western Single Point of Contact (SPOC) center (one of the five national coordination points for IHT during the pandemic in Germany) (ID 4, 5). Dutch and Belgian staff were not properly informed about the coordination center in Münster (ID 2). Nonetheless, experts reported a few IHT (NL to DE), which were organized *via* the coordination point (ID 3).

One of the Dutch experts explained that a lot of distress was caused for Dutch families when patients were transported to Germany organized *via* the coordination points LCPS and Münster. The LCPS does not consider the "human-factor" but simply chooses the next hospital from a list of available locations provided by Münster, even if it is very far away (ID 10, 11, 13). This leads to dramatic consequences for patients and their families because of large distances and, e.g., families needing to stay in holiday apartments to be close to their relatives (ID 11).

> *"[...] there [was] an unbelievable amount of misery [...] in bringing the patients to Germany. That had an impact on the families" (ID 11).*

In cases where Dutch patients were transported far outside the border region, every family was supported by a Dutch social worker and contact person (ID 11). Additionally, the coordination at the national level caused IHT from NL and BE to German hospitals outside the border region, which are not used to receiving patients from other countries (ID 13). Some problems occurred such as foreign helicopters landing in the wrong location (ID 13).

Possible Lessons Learned and Recommendations Regarding Cross-Border Collaboration in the EMR

As emergency situations or dangers do not stop at borders, cross-border collaboration is seen as very important (ID 4, 8, 13, 22):

> *"I find the cross-border collaboration extremely exciting. [...] I think it is right and important to continue working on this topic and such a situation, where there is certainly danger inherent, must never lead us to fall back into situations where there is no longer any cross-border collaboration because also the danger [. . .] does not stop at the borders" (ID 4).*
> *"I think it's very important to have the cross-border collaboration because our region has so many borderlines connected to Germany and Belgium that is for us it is more or less a partner of which you think very often where you could collaborate perhaps" (ID 8).*

Especially when it comes to determining which ambulance could be fastest at the emergency scene or which hospital is nearest, borders and differences in billing (or other) should not play any role (ID 22):

> *"I think our health insurance differs on a number of points, but when it comes to emergency medical care, I don't think that should be a factor. Then it really comes down to human lives and patient care. I think it should take precedence over the rules and other interests" (ID 22).*

More central structures for communication and crisis management plans should be developed for cross-border collaboration in catastrophes and disease outbreaks, such as COVID-19 (ID 2). Further positive aspects related to communication, preparedness, general collaboration, and

TABLE 3 | Positive aspects of the cross-border collaboration in the Euregio Meuse-Rhine (EMR).

Area	Positive aspect	Participants (ID)
Communication	Structured and regular communication is very helpful, especially with EMRIC and the Euregio Meuse-Rhine as an organization	4
Communication	Communication generally functions well across the borders as it is based on a strong network	9
Preparedness	Exercises and preparation within EMRIC are useful for certain scenarios in cross-border collaboration	8
General collaboration	Good collaboration with EMRIC	16
General collaboration	Good collaboration between Eupen (German speaking community in BE) and Aachen (DE) for EMS	16
General collaboration	Considerably less collaboration between the hospitals in Maastricht and Eupen, but still works well	16
General collaboration	Positive cross-border collaboration between hospitals: on operational level in the ICU etc. very good and easy collaboration but on organizational level very complicated and difficult	2
Processes	Processes between South Limburg (NL) and Germany are improving more and more; advanced notification of German EMS to Dutch hospitals works well	10
Best practice exchange	Monitoring and exchange about national COVID-19 measures was helpful to learn from each other and allowed for aligning/adapting hygienic measures, such as wearing masks (especially in the beginning of the pandemic)	18

processes of cross-border collaboration in the EMR are summarized in **Table 3**.

Additionally, the following challenges and lessons learned from the first three waves of the pandemic were described by the experts and should be addressed in the future.

Challenges in General Collaboration

The region still lacks an exchange of best practices and experts highlighted the importance of finding synergies between the different systems. Very significant differences continue to exist between the three healthcare systems. However, the different systems could learn more from each other, especially as they are within such close geographical proximity of one another (ID 1, 2, 6, 22).

> *"[...] So from my point of view there is enormous potential for cross-border collaboration, yes, or... also hospital organization, triage system or emergency room in Maastricht, and also in Heerlen, [...], well I have never experienced that when I was there,[that] there was chaos. In Germany, however, there is regular chaos, that is what is going wrong with us, or differently, [...]" (ID 2).*

As one specific example, the exemplary management of methicillin-resistant *Staphylococcus aureus* (MRSA) infections in NL can be named. This, however, poses a challenge in the case of IHT (except for ICU patients) where a patient is brought to a Dutch hospital (be it from DE or BE) because a lot of administrative steps are involved. Patients will be isolated in the emergency department at the beginning of their hospital stay posing a barrier for cross-border care (ID 21).

Regular cross-border meetings stopped during the pandemic because countries mostly focused on their own systems (ID 5, 21); therefore, it was also assumed that if the neighboring country needed support, they would have requested it (ID 5). Every region focused on its own situation instead of keeping up regular exchanges across the border and learning from each other (ID 5).

> *"This regular exchange has fallen asleep. [...] So 'a great idea, we didn't even have it yet', or 'a cool idea, we'd like to implement that too'. That has not happened in this context because we were all very busy at first [...] and then we say yes, as long as I don't hear anything from the other [...], they are probably still fine [...] To continue [the] existing structures and to continue the exchange and just not have such a cut [...] Well, I think nothing went worse [by not having] this contact, but it might have gone better if we would have had contact" (ID 5).*

The next step for the EMR should be to address how the three countries can support each other's public health system:

> *"I think we need to improve our treaties. [...] when it comes to the Euregion [. . .] for what we are going to do in these kinds of situations. So we've arranged our emergency medical service well, but that's assuming it's about individual patients, and small groups of patients [...]. [. . .] Not in such an overwhelming pandemic really, where the entire public health system is compromised. And the next phase that we need to do is make plans together – with each other, I mean in this region – how we can support the structure of public health of each other, without compromising the functioning. [...] [. . .] how can we [. . .] all make sure within Europe that we can manage that, without having to undermine our normal structure" (ID 20).*

Currently, this expert does not see a solution for this in short term but sees the need for a European healthcare system in the future (ID 20). At the European level, the allocation of patients should be improved by centralization of expertise where patient groups with low numbers but high variability can be treated (ID 20).

However, various barriers were identified to limit the potential of cross-border care, especially in Belgium (ID 19), such as cross-border collaboration within national policy-making:

> *"[. . .] Look, national thinking is just a hindrance, isn't it? If you just see how Maastricht, how close that is to us if you would start working together with it and open and involve things, but, yes... I think that's a utopia. [. . .] We have to focus on the governments after all [. . .] so that [initiative] has to come from above" (ID 19).*

TABLE 4 | Examples of lessons learned and recommendations for general collaboration (based on encountered challenges before and during the first three COVID-19 waves).

Area	Lessons learnt	Recommendations	Participants (ID)
General collaboration	Recommendation	Best practice exchange and synergies between systems	1, 2, 6, 22
	Recommendation	Keeping up regular exchange and learning from each other	5, 21
	Recommendation	Supporting each other's public health system: no solution yet but believe in a European healthcare system and allocation of patients at European level	20
	Recommendation	Inclusion of cross-border care in national policy making	19
	Lesson learnt	Complex administrative steps in case of IHT from BE/DE to NL (because of MRSA measures)	21
	Lesson learnt	Lack of expert cross-border knowledge and related impacts of the pandemic	10, 11, 16, 21, 22
	Lesson learnt	Time and resources are lacking to sustain collaboration in general	8
	Lesson learnt	Uncertainty regarding contact points results in less collaboration between DE and BE compared to DE and NL	1
	Lesson learnt	NL and DE collaborate more because of geographical reasons	9
	Lesson learnt	Collaboration with BE is generally less and stopped mostly during pandemic	3, 8, 21
	Recommendation	Regular cross-border meetings between operational staff (not just at political level)	7
	Recommendation	Language course in medical Dutch for German dispatchers	7
	Lesson learnt	Crisis management teams did not discuss cross-border patient care, IHT nor capacities but focused on citizen-related impacts (incl. border closing)	6
	Lesson learnt	No patients from Belgium were transported to Aachen (DE) anymore as the pandemic progressed	2
	Recommendation	Knowledge about the other systems, staff education, and competences and increase information about legal coverage of operating in other countries	15
	Lesson learnt	Cross-border transports involving detained psychiatric patients are not working smoothly	1

One specific example where differences in legislation led to operational problems during EMS missions is the transport of a detained psychiatric patient based on a psychiatric medical report for compulsory hospitalization since it is not as straightforward when bringing the patient across the border (ID 1).

> *"[...] the transfer of a detained psychiatric patient across the border. There I have the opinion, that that transport can be carried out [and finished] according to the state law, where the transport started. The Dutch think [that] we have to meet at the border crossing point. [. . .] that's the only thing I know where it doesn't work smoothly" (ID 1).*

Some experts had little knowledge about cross-border collaboration and were not aware of the impacts and consequences of the pandemic on the collaboration (for example Euregional meetings, information exchange, and consideration at the national level) (ID 10, 11, 15, 16, 18, 21, 22). Some experts were also not aware of any cross-border agreements before and during the pandemic (ID 10, 13, 16, 22) [e.g., reimbursement (ID 17)]. A summary of the findings is gathered in **Table 4**.

Agreements

While a cross-border agreement on emergency medicine between NL and BE has existed for over 10 years (ID 13), an overall cross-border agreement between Belgium and Germany at the national level including the health insurance companies is missing. Consequently, the exact details of emergency coverage remain unclear (ID 2, 16, 17, 19, 20). One BE expert explains that administrative processes must be checked case by case after, for example, an emergency transportation (ID 20). An agreement between BE and Rheinland-Pfalz (another state in DE) does exist, but negotiations over an agreement between BE and NRW have been ongoing since 2010 (ID 13, 17). Generally, the Belgian EMS system prefers the treatment of patients in Belgian hospitals over other hospitals in the EMR (in DE and NL). Between BE and DE, there is currently no standardized way of communication to handle cross-border emergency transports nor planned IHT (ID 2, 17, 19), partly because it does not seem too relevant for the daily work of EMS in the region (ID 2, 19).

One expert reported that even though certain agreements exist, rumors still emerged in the past that cross-border care had to be paid for by the patient, which is incorrect (ID 19). The expert also saw unclear billing issues as a major challenge as well as uncertainties around the topics of working processes, education of staff, patient transportation, and responsibilities of physicians for patient care (ID 19). The expert further stated that generally, mostly informal agreements and processes exist but hesitancy remains as to whether all the information is available to the expert (ID 19). Information exchange regarding the agreements and processes could be significantly improved (ID 19).

Another expert perceived the existing Euregional agreements as non-applicable during the pandemic and suggests improving those (ID 21). A summary of the findings is gathered in **Table 5**.

Process Changes During the Pandemic

Although cross-border collaboration worked well during the pandemic, emergency and disaster management plans including cross-border care should be developed and agreed upon before such a situation becomes urgent (ID 14, 17):

TABLE 5 | Examples of lessons learned and recommendations concerning formal Euregional agreements (based on encountered challenges before and during the first three COVID-19 waves).

Area	Lessons learnt	Recommendations	Participants (ID)
Formal Euregional agreements	Recommendation	Harmonization of legislation in the EMR, starting with harmonizing operational processes in BE	17
	Lesson learnt	Existing agreement between NL and BE	2, 16, 19, 20
	Lesson learnt	Agreement lacking between DE and BE: uncertainty with health insurance coverage and financial aspects; Case-by-case assessment required	2, 16, 19, 20; 20
	Lesson learnt	Treatment at national level is preferred over cross-border care by BE (EMS and IHT)	2, 19
	Lesson learnt	BE and DE lack standardized communication processes for cross border EMS and IHT missions; partly based on lack of relevance in their daily work	2, 19
	Lesson learnt	Lack of awareness of agreements	10, 13, 16, 22
	Lesson learnt	Lack of awareness also leads to (untrue) rumors	19
	Lesson learnt	Unclear billing and working processes, staff education, patient transportation, CO2 standards of vehicles and responsibilities related to cross-border patient care (especially for BE)	3, 14, 19
	Lesson learnt	Informal agreements in general exist but uncertainty on level of available information	19
	Recommendation	Information exchange could be improved; the care and quality for that exists (for example *via* an international or European platform)	17, 19

"In terms of collaboration […] If I sum up, it went very well, honestly, everyone showed a lot of goodwill for me, [but] it should be written in advance in texts and not when it's the moment to say to each other, but what do we do now?" (ID 14).

In addition, these plans should be tested in large-scale simulations including cross-border collaboration in such pandemic situations (ID 17).

Further, agreements and regulations on cooperation should ideally be the same between all countries (DE-NL, NL-BE, BE-DE) (ID 15).

Material and/or equipment was shared scarcely between different countries in the pandemic because:

"Every country in Europe has had shortages. [...] Every country has reacted very paternalistically. For example, the large stock of masks [...] Germany and both France […] banned the export of masks, which has put other countries in trouble. And nobody was prepared, had such a big stock around" (ID 20).

Support was not provided to other European countries that were struggling from capacity bottlenecks at certain moments in time, while resources and beds in the EMR were still available (ID 22).

"That European solidarity has had practically no role" (ID 22).

A summary of the findings is gathered in **Table 6**.

Knowledge About Availability of Cross-Border Resources

National bed capacity tools could be improved by including live/current bed capacity (including those of ICUs and special hospital departments) from across the borders as well (ID 1, 2, 7, 8, 17, 21) because resources in the EMR are not adequately used at the moment (ID 1, 8). These systems should be compatible with each other and allow information exchange to improve collaboration (ID 21). One central coordination point for IHT could be implemented (ID 2).

Regarding the availability of resources and specialized treatments/departments, it seems difficult to know for the German EMS workers which hospital in NL can offer which treatment at which time (e.g., cardiac catheter examination), as the patient intake rotates between hospitals in the NL region (ID 1). A summary of findings is gathered in **Table 7**.

Communication Between Dispatch Centers

Concerning the communication between the dispatch centers in general, certain multi-language documents from the EMRIC partnership exist, which allow resource requests from neighboring dispatch centers. One expert considered the documents as not user-friendly and too time-consuming. Most dispatchers just directly call the other dispatch centers to ask for help (ID 7).

After requesting an ambulance from The Netherlands, the German dispatch center does not get any updates on the status of the mission until the dispatch center in Maastricht informs them where the patient has been transported to. This is very delayed and insufficient information exchange (ID 7). Consequently, the German dispatch center cannot answer the questions of second callers on the status of an alerted ambulance (e.g., the estimated time of arrival or the global positioning system (GPS) location) (ID 7). A summary of the findings is gathered in **Table 8**.

Technical Issues/Interoperability

A digital information screen exists at the dispatch center Heinsberg (DE), where cross-border information (e.g., on large fire incidents) appears for every dispatcher to see; but there is no connection between this screen and the German dispatching software, thus the information needs to be typed into their system manually (ID 7).

Connecting the dispatch systems in the EMR could improve the visibility of vehicles' locations once dispatched and could allow for translation opportunities, as some terms can be difficult and may lead to confusion (ID 7).

TABLE 6 | Examples of lessons learned and recommendations about process changes (based on encountered challenges during the first three COVID-19 waves).

Area	Lessons learnt	Recommendations	Participants (ID)
Process changes	Lesson learnt	National IHT processes in South Limburg (NL) interfered with regular cross-border agreements (for ex. choosing the closest hospital)	10
	Recommendation	Definition of explicit criteria to transport	12
	Lesson learnt	Little exchange of material or equipment in Europe; Lack of European solidarity (some areas were more affected than others)	20
	Lesson learnt	Procedures and standards for IHT in pandemic situations	13
	Recommendation	The EU could impose standardized crisis management for EU countries	13

TABLE 7 | Examples of lessons learned and recommendations on the availability of cross-border resources (based on encountered challenges before and during the first three COVID-19 waves).

Area	Lessons learnt	Recommendations	Participants (ID)
Availability of cross-border resources	Recommendation	High need for transparency: Implementing live bed capacity numbers in national bed capacity tools, including the ICU and across borders (online cross-border data registration system)	1, 2, 8, 12, 13, 21
	Recommendation	Real-time data gathering in the coordination centers LCPS	12
	Lesson learnt	Inadequacy of resource usage in EMR	1, 8
	Recommendation	Improving compatibility among national registration systems and information exchange	21
	Recommendation	Implementing a central IHT coordination point	2, 13
	Recommendation	Improving transparency for German EMS workers regarding the treatments at certain Dutch hospitals	1
	Recommendation	Improving information exchange regarding available cross-border resources (special resources; GPS locations)	7

TABLE 8 | Examples of lessons learned and recommendations concerning communication and requests for help between dispatch centers (based on encountered challenges before and during the first three COVID-19 waves).

Area	Lessons learnt	Recommendations	Participants (ID)
Communication and request for help between dispatch centers	Lesson learnt	Cross-border request of resources possible *via* multi-lingual EMRIC documents; documents are time-consuming and complex therefore dispatchers prefer direct communication (DE, NL, BE)	7
	Lesson learnt	Delayed and ineffective information exchange after request for help from NL was issued by DE; DE cannot update secondary callers on ambulance status (incl. time of arrival)	7

One expert explains a technical issue which caused a delay in alerting the emergency physician on German ground by a German ambulance team close to the Dutch border (ID 6). This emphasizes the importance of securing a mobile phone connection with the team's own dispatch center (ID 6).

> *"But then the problem came to light that they did not have a good connection to the dispatch center via the work cell phone and the colleague then had to call with the private cell phone afterward because [the call] always ended up in The Netherlands. That must no longer be the case today. This is a technical problem, I think, that can be solved. [...] That you can really reach [. . .] the dispatch center that guides you and sends you in with support. And if you have a Dutch person on your ear in such a situation, who may speak German or English but then you have a resuscitation, [...]. That's stupid then. [...] but that can of course also be optimized by properly setting the cell phones that we have on the vehicles and routing them correctly. [...]" (ID 6).*

This was also explained by another expert, as the radio signal does not remain intact near the Dutch border (ID 7). In addition, communication between the dispatch center in Maastricht and the German helicopter remains difficult (ID 8). Even though a working group was set up for cross-border radio communication in the EMR, this is still an important and problematic issue for two experts (ID 7, 14). A summary of the findings is gathered in **Table 9**.

DISCUSSION

The aim of this study was to demonstrate the impacts of and the lessons learned from the first three COVID-19 waves on the cross-border collaboration in EMS and IHT in the EMR. The interviewed experts were from various backgrounds, including those working at the political and crisis management level, medical directors (EMS), dispatch center managers, physicians, and dispatch center staff, firefighters, and EMS practitioners. The majority of those interviewed essentially agreed that cross-border collaboration in the EMR is indispensable. The present study highlights that the logistical challenges and disruptions widely experienced due to the ongoing pandemic call for improved and more robust collaboration across borders. While

TABLE 9 | Examples of lessons learned and recommendations for technical issues and interoperability (based on encountered challenges before and during the first three COVID-19 waves).

Area	Lessons learnt	Recommendations	Participants (ID)
Technical issues/Interoperability	Lesson learnt	Dispatch center Heinsberg: Major cross-border incidences are presented on a large information screen but the information is not directly connected to the dispatch system and can only be entered manually into the German dispatch system	7
	Recommendation	Dispatch systems in the EMR should be connected to improve visibility and communication (incl. resource locations and status, automatic translator)	7
	Lesson learnt	Radio and telephone compatibility is crucial but currently largely lacking [incl. (cellphone) service problems in border regions] (between foreign EMS and dispatch centers)	3, 6, 7, 14
	Lesson learnt	Radio communication between NL and the German helicopter remains difficult; A Dutch radio is currently built into the helicopter to solve communication issues	3, 8

the capabilities that lie within the EMR have been highlighted before (9, 10, 36), the impacts of the pandemic make these even more apparent. A huge potential lies in exchanging best practices, organizing collaborative exercises, working together, and supporting each other with resources when needed (7). Still, this study reveals that, generally, prior to and during the pandemic, several issues and problems remain which hinder or handicap cross-border collaboration. This has also been identified by the Interreg-funded project PANDEMRIC, which analyses the cross-border cooperation within the EMR and presented the first results in two symposia in 2021 (37). While a common cross-border or even European approach in handling EMS and IHT missions or even general healthcare is sought, it does bring up challenges at the national policy-making level (3, 38). Fragmentation in the countries' national approaches to tackling the pandemic became clear and hindered the cross-border collaboration in the EMR to the extent of a temporary near-standstill. This was a result of the national measures and processes causing uncertainty and hindering widely established habits with the onset of the pandemic. In addition, this study identified several recommendations and lessons learned regarding the general collaboration, formal Euregional agreements, process changes, availability of cross-border resources, communication between dispatch centers, and the interoperability of technical systems. Knowledge regarding already existing official cross-border agreements could be improved at a larger scale while working toward even more legalized standardized cross-border procedures (3, 9, 36, 38). With the experience of the COVID-19 crisis, a new fresh look at the relevance and importance of EU Cross-Border Mechanisms as suggested during the EU presidency of Luxembourg in 2015 might reveal a better understanding of the need for a comprehensive and targeted set of tools that provide a sound legal basis for deviating from conflicting national regulations in the interest of necessary cross-border arrangements (39).

At a national level, cross-border concerns were not often considered in COVID-19 related policymaking and the implementation of national measures. Experts also reported that regional crisis management teams did not discuss the topic in depth. However, data on COVID-19 cases and bed capacity was exchanged during the course of the pandemic in the EMR. While two of the main characteristics of EMR are accessibility and easy transfer (10), the fragmentation among national measures such as border closures did not only cause national borders to become more visible again but also brought up uncertainty regarding operational processes. Other studies have also identified the fragmentation in the EU regarding nationally implemented COVID-19 measures (4, 5, 9). Previous studies highlighted the need for better European structures and a better delegation of tasks (3–5, 38, 40). The purchase and distribution of certain equipment call for joint procurement and standardized processes (4, 5, 40). This becomes especially apparent in the studied cross-border region, where countries often face similar obstacles or could help each other even better if standardized structures or agreements were in place and considered nationally (3). While a recent report by the project euPrevent COVID-19 states that national measures were regularly communicated across the border *via* one main contact point (6), this information seemed to have lacked at the operational level. Thus, a clear distinction must be made here between political decision-making and information reaching the operational workers.

Almost all challenges in this study can be attributed to the lack of standardized cross-border information exchange among the relevant stakeholders. Certain measures implemented by the EMRIC partnership have facilitated information exchange to some extent. In the EMR, additionally, a Euregional dashboard has been created showing specific COVID-19 data in the region (41). At the operational level and especially from the perspective of the dispatch centers, the implementation of real-time data exchange (on EMS and hospitals resources) and interoperable systems across the border would be a major improvement to request and offer help. Other EMS literature highlights the importance of continuous data collection and exchange between stakeholders involved at an operational level (3, 9). The main issues related to this concern the allocation of resources, lack of and dispatch of resources, as well as demand forecasting and the scheduling of IHT (2). In cross-border missions, these factors are even further highlighted. This study demonstrates that once a foreign resource has crossed the border, information exchange often completely stops, causing communication and demand-planning issues. Thus, systems and processes

related to information exchange at the operational level need to be harmonized.

The well-established collaboration supported by the EMRIC group helped to facilitate structured and regular communication, also during the pandemic, which has also been identified in previous findings (6, 9). However, overall, the crisis also highlighted the limitations of the collaboration that is mainly based on mutual understanding and is missing any robust legal foundation or clear political mandate. The trust and mutual understanding developed during the long-term collaboration in this border region helped to find informal solutions and alternative practices to decisions on a national level that interfered with the established cross-border operational processes in order to maintain a level of continuity even during the crisis. But the COVID-19 "stress-test" of existing cross-border collaboration clearly shows the need for new more formal and legally binding arrangements to improve the resilience of public safety in the EMR in crises. Further, our study revealed major differences in the views of experts at the managerial/political level and those at the operational level, especially regarding the feasibility of measures implemented before and during the crisis. This also indicates some weaknesses in the governance structure of the cross-border collaboration on public safety in the region. The perceived detachment of leadership from operations can also be attributed to the informality of the governance structure and the absence of formal procedures and processes that guarantee transparency and participation.

Throughout the management of hospitalizations and ICU patients, cross-border collaboration remained intact at the beginning of the pandemic. Early findings support this, as various patients have been transported to other EU countries in the early phases of the pandemic (42). Learning from each other's experiences across the border has been identified as helpful in adapting national decision-making. Belgium for ex., conducted a study to learn from other EU countries by investigating surge capacity strategies in a selected number of countries, including Germany and The Netherlands (43). However, once national organizational structures were implemented to manage the IHT of patients with COVID-19, they overruled cross-border habits for patient transfers within the EMR, causing a clear gap between political decision-making and operational practicality. Thus, benefits such as the proximity of facilities were neglected during crucial decision-making processes. The need for a supra-regional/international system for patient allocation during COVID-19 based on shortages of ICU beds and other resources has been highlighted in previous findings (9, 40, 44) and underlines this identified issue in this study. Another study highlights the need for common infrastructures to monitor cross-border resources in the EU. The authors state that the transfer of patients across national borders was the first step toward improved allocation and solidarity (40). However, a high variety of available infrastructures to report hospital capacity was identified, especially across the EU. Some systems allow for real-time data collection and others did not have appropriate data infrastructures to allow the daily recording of numbers (9, 40).

RECOMMENDATIONS

Generally, the following recommendations can be made for cross-border collaboration in EMS and IHT in the EMR:

- The cooperation would benefit from and be further strengthened by formal and legally binding Euregional agreements on operational processes to organize cross-border collaboration in EMS and IHT.
- Knowledge about official Euregional agreements and operational processes needs to be prioritized at the policy and operational level and governance structures need to improve participation and transparency.
- Considering and facilitating respective cross-border collaboration at the national policy-making level is essential to enhance cooperation among the neighboring countries.
- Establishing information exchange and technical system compatibility at the Euregional level to facilitate cross-border collaboration among the involved actors.
- Involving representatives of neighboring services in regional crisis management discussions to encourage information exchange and adaption of processes and enhance cooperation among the three countries.
- Identification and application of best practices and synergies at the Euregional level to encourage cross-border collaboration among the involved actors.

LIMITATIONS

The study and its results have several limitations: Establishing contacts to experts was extremely difficult during the pandemic as all experts and potential interviewees were involved and responsible as front-line staff of the EMS services and hospitals prioritizing their medical and managerial duties. Therefore, the number of respondents is not as comprehensive as desired and originally intended. In addition, due to the busy schedule of the respondents, it turned out to be not feasible to have complete coverage for each of the different relevant stakeholder categories (medical director EMS, hospital/emergency physician, political level/crisis management team, ambulance/firefighting service, dispatch center) in each region. Due to the pandemic situation, the interviews were performed online (or by telephone if technical difficulties occurred).

The abovementioned challenges may limit the generalization of our findings. Further, the study only includes the results of the first three waves of the COVID-19 pandemic.

CONCLUSION

As emergency situations or public health threats do not stop at borders, the cross-border collaboration of regional public safety services is highly important and in many European cross-border regions embedded in the European identity of the regional population. Falling back on stringent national reorganization and policy decision-making when trying to manage major crises like the pandemic should not disenable or hamper cross-border

collaboration. The resilience of public safety in cross-border regions depends on sound and reliable regulations and legal tools that allow for the necessary cross-border support. To be effective, it is imperative that healthcare professionals at all levels (from operational up to political) are well-informed about cross-border resources and competencies to strengthen the cooperation among the EU Member States. Governance structures and decision-making for cross-border collaboration need to be based on robust legal instruments and the principles of transparency and participation. Identifying which ambulance could be fastest at the emergency scene or which suitable hospital is closest for a patient needing immediate care independent of national borders and organizational differences is an achievement of European collaboration. This pandemic clearly calls for the improvement of instruments and the political will and understanding to further strengthen cross-border collaboration and make the best use of scarce resources based on solidarity and mutual understanding.

DATA AVAILABILITY STATEMENT

The qualitative datasets presented in this article are not readily available because of privacy and data protection rules. Requests to access the datasets should be directed to Anja Sommer, ansommer@ukaachen.de; Cassandra Rehbock, crehbock@ukaachen.de. Any additional data used is available in the article or in the **Supplementary Material**.

ETHICS STATEMENT

The study received ethical approval by the Ethics Committee of the Medical Faculty of RWTH Aachen, Germany (registration numbers: EK 390/20, CTC-A 20-417). The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

AS, CR, EP, MG, SB, and TK conceptualized and designed the study. AS and CR were the coordinating investigators and analyzed the findings. CV provided background information and illustrations. AS, CR, MG, SC, and SD conducted the interviews. AS, CB, CR, and SD coded the interviews. HS, SB, and TK supervised the work. AS drafted the manuscript and revised it. CR critically revised the manuscript. All authors revised and approved the manuscript.

FUNDING

The study has been initiated and supported by the International Knowledge and Information Centre in public safety (IKIC) and received partial funding from Interreg EMR funds, funding number EMR77, website: https://www.ikic-publicsafety.eu/.

ACKNOWLEDGMENTS

We would like to thank all interviewees who took the time and effort to participate in this study even during such critical times in which they were needed the most—this makes our work very meaningful and insightful. We would like to thank Matthieu Michels who supported us in the translation and interpretation of some of the interviews. We also would like to thank Stefanie Disbeschl for the constructive linguistic and grammatical feedback. Last but not least, we thank the IKIC-project consortium for the feedback and comments throughout our work.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.841013/full#supplementary-material

REFERENCES

1. Garcia-Castrillo L, Petrino R, Leach R, Dodt C, Behringer W, Khoury A, et al. European Society for Emergency Medicine position paper on emergency medical systems' response to COVID-19. *Euro J Emerg Med.* (2020) 27:174–7. doi: 10.1097/MEJ.0000000000000701
2. Reuter-Oppermann M, van den Berg PL, Vile JL. Logistics for emergency medical service systems. *Health Syst.* (2017) 6:187–208. doi: 10.1057/s41306-017-0023-x
3. Wismar M, van Ginneken E, Palm W, Figueras J, Ernst K. *Cross-Border Health Care in the European Union - Mapping and Analysing Practices and Policies*. (2010).
4. Gontariuk M, Krafft T, Rehbock C, Townend D, van der Auwermeulen L, Pilot E. The European Union and Public Health Emergencies: expert opinions on the management of the first wave of the COVID-19 pandemic and suggestions for future emergencies. *Front Public Health.* (2021) 9:698995. doi: 10.3389/fpubh.2021.698995
5. Forman R, Mossialos E. The EU response to COVID-19: from reactive policies to strategic decision-making. *J Common Market Stud.* (2021) 59:56–68. doi: 10.1111/jcms.13259
6. Horstman K, Hackert V, Philippsen D, Kamenshikova A, Diemingen L, van der Zanden B, et al. *The development of COVID-19 in the border area of the Netherlands, North Rhine-Westphalia and Belgium.* (2021). Available online at: www.euregionalhealthatlas.eu (accessed January 21, 2022).
7. Legido-Quigley H, Glinos IA, Baeten R, McKee M, Busse R. Analysing arrangements for cross-border mobility of patients in the European Union: a proposal for a framework. *Health Policy.* (2012) 108:27–36. doi: 10.1016/j.healthpol.2012.07.001
8. General Secretariat of the Benelux Union. *Patients Without Borders- Cross-Border Patient Flows in the Benelux* (2016). Available online at: https://www.benelux.int/nl/publicaties/publicaties-overzicht/patienten-zonder-grenzen-grensoverschrijdende-patientenstromen-de-benelux/ (accessed December 1, 2021).
9. Fabienne Leloup. *Research for REGI Committee – Cross-Border Cooperation in Healthcare*. Brussels: European Parliament, Policy Department for Structural and Cohesion Policies (2021). Available online at: https://bit.ly/2Z9b6Ll (accessed December 1, 2021).
10. Euregio Maas-Rhein. *EMR 2020 - Eine Zukunftsstrategie für die Euregio Maas-Rhein.* (2013). Available online at: https://euregio-mr.info/de/themen/ (accessed December 4, 2021).
11. Paquay M, Chevalier S, Sommer A, Ledoux C, Gontariuk M, Beckers SK, et al. Disaster management training in the euregio-meuse-rhine: what can we learn from each other to improve cross-border practices? *Int J Disast Risk Reduct.* (2021) 56:102134. doi: 10.1016/j.ijdrr.2021.102134

12. Consolidated version of the treaty on the functioning of the European Union. *Off J Euro Union*. C326/47-390 (2012).
13. Consolidated version of the Treaty on European Union. *Off J Euro Union*. C326/13-45 (2012).
14. European Commission. *Report from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions - EU border regions: Living labs of European integration*. (2021). Available online at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0393 (accessed December 1, 2021).
15. Townend DMR, van de Pas R, Bongers L, Haque S, Wouters B, Pilot E, et al. What is the role of the European Union in the COVID-19 pandemic? *Med Law*. (2020) 39:249–68.
16. European Outline Convention on Transfrontier Co-operation Between Territorial Communities or Authorities. *Off J Euro Union. C326/13-45*. Madrid: Council of Europe (1980). Available online at: https://www.coe.int/en/web/conventions/full-list?module=treaty-detail&treatynum=106 (accessed January 20, 2022).
17. Regulation (EC) No 1082/2006 of the European Parliament and of the Council of 5 July 2006 on a European grouping of territorial cooperation (EGTC). *Off J Euro Union*. 210/19–24. (2006).
18. Directive 2011/24/EU of the European Parliament and of the Council of 9 March 2011 on the application of patients' rights in cross-border healthcare. *Off J Euro Union*. 88/45–65 (2011).
19. Eurostat. *Country Codes*. (2021). Available online at: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Country_codes (accessed August 14, 2021).
20. Healthy Belgium. *COVID-19 Mortality*. (2021). Available online at: https://www.healthybelgium.be/en/health-status/covid-19-crisis/covid-19-mortality (accessed August 11, 2021).
21. RIVM. In derde golf sterke stijging ziekenhuisopnames jongere leeftijdsgroepen. *Rijksinstiuut voor Volksgezondheid en Milieu*. (2021). Available online at: https://www.rivm.nl/nieuws/in-derde-golf-sterke-stijging-ziekenhuisopnames-jongere-leeftijdsgroepen (accessed December 1, 2021).
22. RIVM. Verschil tussen eerste en tweede golf corona. Rijksinsituut voor Volksgezondheid en Milieu. (2020). Available online at: https://www.rivm.nl/documenten/verschil-tussen-eerste-en-tweede-golf-corona (accessed August 11, 2021).
23. Schilling J, Lehfeld A-S, Schumacher D, Ullrich A, Diercke M, Buda S, et al. Krankheitsschwere der ersten COVID-19-Welle in Deutschland basierend auf den Meldungen gemäß Infektionsschutzgesetz. *J Health Monitor*. (2020) 5:1–20. doi: 10.25646/7169
24. ZDF. *Deutschland und Europa - Corona-Wellen im Zeitraffer*. (2021). Available online at: https://www.zdf.de/nachrichten/video/panorama-corona-vierte-welle-100.html (accessed August 11, 2021).
25. Droogh JM, Smit M, Hut J, de Vos R, Ligtenberg JJ, Zijlstra JG. Inter-hospital transport of critically ill patients; expect surprises. *Critical Care*. (2012) 16:1–6. doi: 10.1186/cc11191
26. Feazel L, Schlichting AB, Bell GR, Shane DM, Ahmed A, Faine B, et al. Achieving regionalization through rural interhospital transfer. *Am J Emerg Med*. (2015) 33:1288–96. doi: 10.1016/j.ajem.2015.05.032
27. Gustafsson M, Wennerholm S, Fridlund B. Worries and concerns experienced by nurse specialists during inter-hospital transports of critically ill patients: a critical incident study. *Intens Crit Care Nurs*. (2010) 26:138–45. doi: 10.1016/j.iccn.2010.01.002
28. van Houtum H. An overview of Europaen geogrephical research on borders and border regions. *J Borderlands Stud*. (2000) XV:57–83. doi: 10.1080/08865655.2000.9695542
29. EMRIC. *What is EMRIC?* (2021). Available online at: https://emric.info/emric/en/citizens/what-is-emric (accessed December 19, 2021).
30. EMRIC. *Mehrjahresplan 2014-2019*. Simmerath: EMRIC (2012). Available online at: https://emric.info/en/professionals/publications/multiannual-plan/multi-anual-plan-2014-2019 (accessed December 10, 2021).
31. IKIC Public Safety. (2021). Available online at: https://www.ikic-publicsafety.eu/project-overview.html (accessed December 19, 2021).
32. Healthy Belgium. *The Various Emergency Services for Emergency Assistance*. (2021). Available online at: https://www.healthybelgium.be/en/key-data-in-healthcare/emergency-medical-and-psychosocial-assistance/organisation/via-a-112-call-to-a-hospital-care-process-for-an-individual/the-various-emergency-services-for-emergency-assistance (accessed January 20, 2022).
33. *Inspectie Gezondheidszorg en Jeugd*. Ambulancezorg (2021). Available online at: https://www.igj.nl/zorgsectoren/eerstelijnszorg/ambulancezorg (accessed January 26, 2022).
34. *Uniform Begrippenkader Ambulancezorg, versie 4.0*. (2021). Available online at: https://www.ambulancezorg.nl/themas/ambulancezorg-in-nederland/uniform-begrippenkader-ambulancezorg/wat-is-het-uniform-begrippenkader-ambulancezorg (accessed January 20, 2022).
35. Gale NK, Heath G, Cameron E, Rashid S, Redwood S. Using the framework method for the analysis of qualitative data in multi-disciplinary health research. *BMC Med Res Methodol*. (2013) 13:117. doi: 10.1186/1471-2288-13-117
36. European Commission. *Enhancing Healthcare Cooperation in Cross-Border Regions* (2018).
37. Interreg - Pandemric. *PANDEMRIC*. (2021). Available online at: https://pandemric.info/ (accessed August 5, 2021).
38. Svensson S. Health policy in cross-border cooperation practices: the role of Euroregions and their local government members. *Territory Polit Govern*. (2017) 5:47–64. doi: 10.1080/21622671.2015.1114962
39. Sielker F. The European Commission's proposal for a cross-border mechanism (ECBM): potential implications and perspectives. *J Prop Plann Environ Law*. (2018) 10:219–39. doi: 10.1108/JPPEL-08-2018-0024
40. Winkelmann J, Webb E, Williams GA, Hernández-Quevedo C, Maier CB, Panteli D. European countries' responses in ensuring sufficient physical infrastructure and workforce capacity during the first COVID-19 wave. *Health Policy*. (2021). doi: 10.1016/j.healthpol.2021.06.015
41. Interreg. *Euregional Health Atlas - Euregional Covid-19 Dashboard*. (2021). Available online at: http://euregionalhealthatlas.eu/covid19.html (accessed December 15, 2021).
42. Winkelmann J, Scarpetti G, Hernandez-Quevedo C, van Ginneken E. *How Do the Worst-Hit Regions Manage COVID-19 Patients When They Have No Spare Capacity Left?* (2020). Available online at: https://analysis.covid19healthsystem.org/index.php/2020/04/24/how-do-the-worst-hit-regions-manage-covid-19-patients-when-they-have-no-spare-capacity-left/ (accessed December 7, 2021).
43. van de Voorde C, Lefèvre M, Mistiaen P, Detollenaere J, Kohn L, van den Heede K. *Assessing the Management of Hospital Surge Capacity in the First Wave of the COVID-19 Pandemic in Belgium*. Brussels: Belgian Health Care Knowledge Centre (KCE) (2020). Available online at: www.kce.fgov.be (accessed December 1, 2021).
44. Adam EH, Flinspach AN, Jankovic R, de Hert S, Zacharowski K. Treating patients across European Union borders: an international survey in light of the coronavirus disease-19 pandemic. *Eur J Anaesthesiol*. (2021) 38:344–7. doi: 10.1097/EJA.0000000000001423

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers in Public Health

ORIGINAL RESEARCH
published: 30 March 2022
doi: 10.3389/fpubh.2022.808148

Differences in the Awareness and Knowledge of Radiological and Nuclear Events Among Medical Workers in Japan

Kanae Ochiai[1]*, *Tomo Oka*[2], *Nagisa Kato*[1], *Yuji Kondo*[3], *Yasuhiro Otomo*[1] and *Raymond E. Swienton*[4]

[1] Trauma and Acute Critical Care Medical Center, Tokyo Medical and Dental University Hospital of Medicine, Tokyo, Japan, [2] Emergency Medical Center, Fujisawa City Hospital, Kanagawa, Japan, [3] Department of Emergency, Japanese Red Cross Medical Center, Tokyo, Japan, [4] University of Texas Southwestern Medical Center, Dallas, TX, United States

Background: Previous research revealed a lack of comfort and knowledge regarding nuclear and radiological events among medical staff. We investigated the awareness and knowledge of radiological and nuclear events among the Japanese medical staff by comparing differences by occupation (doctors, nurses, and other medical specialists).

Methods: We conducted a cross-sectional questionnaire survey among trainees undergoing Japanese disaster medical training courses between July 2014 and February 2016. The differences by occupation were evaluated for all questions on awareness and knowledge concerning disasters or radiological and nuclear events and demographics.

Results: Among the occupations, there were significant differences in the willingness to work onsite based on the types of disaster, familiarity with the national disaster medical response system, the accuracy rate of some knowledge about medical practice and the risk, and demographic characteristics such as practical experience and educational degree. The accuracy rates of responses to some questions on knowledge were very low in all occupations.

Conclusion: There were significant differences in awareness and knowledge of radiological and nuclear events by occupation. We believe that the results can be used to develop and modify the content of training courses on radiological and nuclear events to make such courses beneficial for each healthcare worker.

Keywords: radiological, nuclear, training, education, preparedness, occupation

OPEN ACCESS

Edited by:
Laurits Nielsen, University College Copenhagen, Denmark

Reviewed by:
Mikkel Toft, Danish Red Cross, Denmark
Peter Fristrup, Danish Emergency Management Agency, Denmark
Nina Baron, University College Copenhagen, Denmark

***Correspondence:**
Kanae Ochiai
kana_hina_kiss@yahoo.co.jp

Specialty section:
This article was submitted to Disaster and Emergency Medicine, a section of the journal Frontiers in Public Health

Received: *03 November 2021*
Accepted: *04 February 2022*
Published: *30 March 2022*

Citation:
Ochiai K, Oka T, Kato N, Kondo Y, Otomo Y and Swienton RE (2022) Differences in the Awareness and Knowledge of Radiological and Nuclear Events Among Medical Workers in Japan. Front. Public Health 10:808148. doi: 10.3389/fpubh.2022.808148

INTRODUCTION

Although radiological and nuclear events are rare, preparedness for such events is necessary because they can cause serious damage. Physical and mental health issues have been long-term problems in the aftermath of nuclear accidents in Fukushima and Chernobyl (1–3). Moreover, the Fukushima nuclear disaster caused severe damage to the economy, as industrial shipments from Fukushima fell to 85% in 2011 (1). It also gave rise to social problems such as discordance in families and communities (1). Therefore, in recent years, many countries have put in place preparedness for chemical, biological, radiological, nuclear, and explosive (CBRNE) disasters. Such preparedness

includes the construction of a network of biological dosimetry (4), investigation of the equipment or systems required for CBRNE disasters at hospitals and emergency medical services (5–7), and assessment of education and training for CBRNE disaster response (8–10). The recent coronavirus disease 2019 (COVID-19) pandemic also has the characteristics of a mass casualty, and intensive care unit (ICU) preparedness to adequately address it became an urgent global concern. Therefore, several guidelines for planning and roadmaps that enable ICU preparedness have been established (11–15). The COVID-19 pandemic was too intense to manage, and most healthcare providers realized the importance of preparedness. Efficient educational methods relevant to CBRNE disasters are needed.

Japan has experienced some major radiological and nuclear events, such as the Fukushima No. 1 nuclear power plant accident and the nuclear bomb detonations in Hiroshima and Nagasaki (16). Japanese people are aware of the dangers of radiological and nuclear events because there are 60 nuclear plants across the nation, and 8 of these were in operation as of December 2021 (17), despite this country being seismically active. Japanese also have anxiety about radiological and nuclear events based on the Fukushima nuclear power plant accident experience and their knowledge of the history of nuclear bombings.

Dallas et al. (18) conducted a questionnaire survey to compare American and Japanese medical personnel's willingness to respond to, their familiarity with, and their relevant knowledge of, radiological and contamination risks; they found that most responders were still very uncomfortable with radiological and nuclear events. The survey targeted people who participated in various medical and disaster conferences and courses in the USA and Japan. Compared to US respondents, Japanese respondents were less likely to be willing to work in a dirty bomb scenario (−27%) or treat casualties at their hospital (−5.3%), respectively. Concurrently, they indicated that Japanese respondents had insufficient knowledge about these events, such as knowledge about personal protective equipment (PPE) or internal radioactive contamination.

In Japan, the disaster medical assistance team (DMAT), which consists of doctors, nurses, and logistics personnel, is a nationwide medical system that is activated when large-scale disasters occur. Although there are other disaster response systems that consist of registered members, DMAT contains the largest number of registrants. The DMAT training course was modified following the Great East Japan Earthquake (19); however, it does not contain educational content for CBRNE disasters. This is because activities that need to be performed during CBRNE disasters are distinctive and accompanied by significant hazards for general healthcare workers. Therefore, it would be effective to separate the training program for CBRNE disasters from the normal disaster training course and to target medical staff who are knowledgeable about the medical team's activities during normal large-scale disasters (20). Based on the different occupations, the DMAT training course includes separate programs for doctors, nurses, and logistics personnel because of differences by occupation in roles at disaster sites and the educational basis (19). There might also be some differences in the level of awareness or knowledge of CBRNE disasters by different occupations.

Therefore, we conducted a survey of the Japan DMAT training course trainees using the same anonymous questionnaire that Dallas et al. (18).

This survey aimed to determine the level of awareness and knowledge of radiological and nuclear events of medical staff with interest in disaster medicine who were able to be the main member to work in such disasters in Japan. We also aimed to investigate the differences between doctors, nurses, and other specialists. Moreover, we also investigated suggestions for improvement of advanced CBRNE disaster education and training courses, considering the different backgrounds of the medical workers.

MATERIALS AND METHODS

We conducted a cross-sectional questionnaire survey. In this survey, paper questionnaires were distributed to trainees who participated in the Japan DMAT training course in Tokyo (between July 2014 and February 2016) and Hyogo (between September 2014 and February 2016). The trainees were hospital medical staff who intended to work at disaster sites during large-scale disasters. Doctors and nurses with any specialty could participate in this course. Logistics personnel included hospital clerks, pharmacists, radiologists, and other medical professional technologists. The questionnaires were distributed during the course and collected until the end of each course.

The questionnaire, which was the same Japanese version used in the previous survey (18), contained 22 questions divided into four sections: 1) willingness to manage exposed casualties, 2) familiarity—local and country disaster system, 3) familiarity—radiological and nuclear contamination risks, and 4) demographic and practice description. Five questions were about willingness to work during CBRNE disasters or familiarity with such disasters, six were to verify respondents' knowledge about radiological and nuclear contamination, and 11 were about respondents' background and demographic characteristics. The English version of this questionnaire is shown in the previous article (18) and the **Supplementary Material**.

The Japan DMAT secretariat implemented the distribution and collection of the questionnaires. The data obtained from the questionnaires were analyzed at the Department of Acute Critical Care and Disaster Medicine, Tokyo Medical and Dental University.

To evaluate the differences by occupation, the Kruskal-Wallis test was used for continuous variables and the chi-square test for categorical variables. If there were significant differences on univariate analysis, binary logistic regression analysis adjusted for year of birth, sex, and radiation/nuclear experience was conducted for the question items. A $P < 0.05$ was considered statistically significant. All analyses were performed using IBM

Abbreviations: CBRNE, Chemical, Biological, Radiological, Nuclear, and Explosive; COVID-19, Coronavirus disease 2019; DMAT, Disaster medical assistance team; ICU, Intensive care unit; IRB, Institutional Review Board; PPE, Personal protective equipment.

SPSS Statistics for Windows, version 25 (IBM Corp., Armonk, N.Y., USA).

The survey was approved by the Institutional Review Board (IRB) of the University of Texas Southwestern Medical Center, which reported the previous survey (18). The IRB determined on November 18, 2013, that this survey was exempt in accordance with 45 CFR 46.101(b) (IRB number: STU 082013-073).

RESULTS

During the survey period, 1,620 questionnaires were distributed during the Japan DMAT training courses. We obtained responses from 904 respondents (55.8%). Since we excluded respondents whose type of occupation (doctor, nurse, or logistics) data were missing, 774 responses (47.8%) were finally analyzed. Regarding occupation, 342 (44.2%), 284 (36.7%), and 148 (19.1%) of respondents were doctors, nurses, and logistics personnel, respectively.

Demographic and background data are shown in **Table 1**. Significant differences were observed among occupations in terms of year of birth ($p < 0.05$) and practical experience of disasters or public health emergencies; the doctors were the most experienced ($p < 0.01$), and the nurses were the least experienced ($p < 0.05$). There were significantly fewer male nurses ($p < 0.01$), and nurses were the least affiliated with a disaster medical response team ($p < 0.01$). Doctors were most likely doctorate holders ($p < 0.01$). Logistics personnel who participated in the Japan DMAT training courses rarely belonged to a university ($p < 0.01$), but they tended to complete multiple disaster training courses ($p < 0.05$). No significant differences were found in other background data by occupations. The rate of respondents who had experience in the radiation/nuclear science field was 16.8% (doctor 16.7%, nurse 15.8%, and logistics 18.9%).

The most important disaster type that may prevent medical staff from coming to work was nuclear bomb detonation for all occupations (**Figure 1**). The percentage of nurses who consider biological disasters the most important event preventing them from going to work was lower than those of other occupations ($p < 0.01$). Logistics personnel tended to consider that the nuclear power plant accident was not so important to prevent them from coming to work ($p < 0.05$). The most important condition for medical staff to be willing to come to work after a nuclear detonation was their family's safety, except for nurses ($p < 0.01$; **Figure 2**). Some respondents never intended to work after a nuclear detonation, and the rate of unwillingness was the highest among nurses ($p < 0.05$). However, the significant

TABLE 1 | Respondents' demographic and background data.

		Occupation		
		Doctor ($n = 342$)	**Nurse ($n = 284$)**	**Logistics ($n = 148$)**
Year of birth, median (IQR)		1977 (1970, 1982)	1980 (1975, 1984)	1982 (1977, 1986)
Sex, *n* (%)	Male	283 (84.9)	129 (45.7)	135 (91.2)
Country of medical practice, n (%)	Japan	342 (100.0)	284 (100.0)	148 (100.0)
Highest educational degree, n (%)	Undergraduate	6 (1.8)	8 (2.8)	3 (2.0)
	Graduate	159 (46.5)	120 (42.3)	113 (76.4)
	Doctorate	135 (39.5)	10 (3.5)	11 (7.4)
	No response	42 (12.3)	146 (51.4)	21 (14.2)
Type of medical practice, n (%)	Clinic	1 (0.3)	0 (0.0)	0 (0.0)
	Hospital	267 (78.1)	227 (79.9)	126 (85.1)
	University	70 (20.5)	55 (19.4)	15 (10.1)
	Other	3 (0.9)	1 (0.4)	3 (2.0)
	No response	1 (0.3)	1 (0.4)	4 (2.7)
Experience of radiation/nuclear science field, n (%)	Yes	57 (16.7)	45 (15.8)	28 (18.9)
Field of specialty, n (%)		Emergency 130 (38.0)		Clerk 27 (18.2)
		Surgical 126 (36.8)		Radiologist 22 (14.9)
		Internal 43 (12.6)	NA	Other technologists 74 (50.0)
		Radiology 5 (1.5)		Unknown 25 (16.9)
		Other 38 (11.1)		
Affiliation with some type of disaster response team, n (%)	Yes	218 (63.7)	149 (52.5)	95 (64.2)
Experience of responding to a disaster or emergency, n (%)	Yes	76 (22.2)	39 (13.7)	24 (16.2)
Number of training courses completed, n (%)	0	302 (88.3)	258 (90.8)	138 (93.2)
	1	30 (8.8)	17 (6.0)	8 (5.4)
	2–4	7 (2.0)	7 (2.5)	1 (6.8)
	5 or more	0 (0.0)	0 (0.0)	1 (6.8)
	No response	3 (0.9)	2 (0.7)	0 (0.0)

IQR, interquartile range; NA, not applicable.

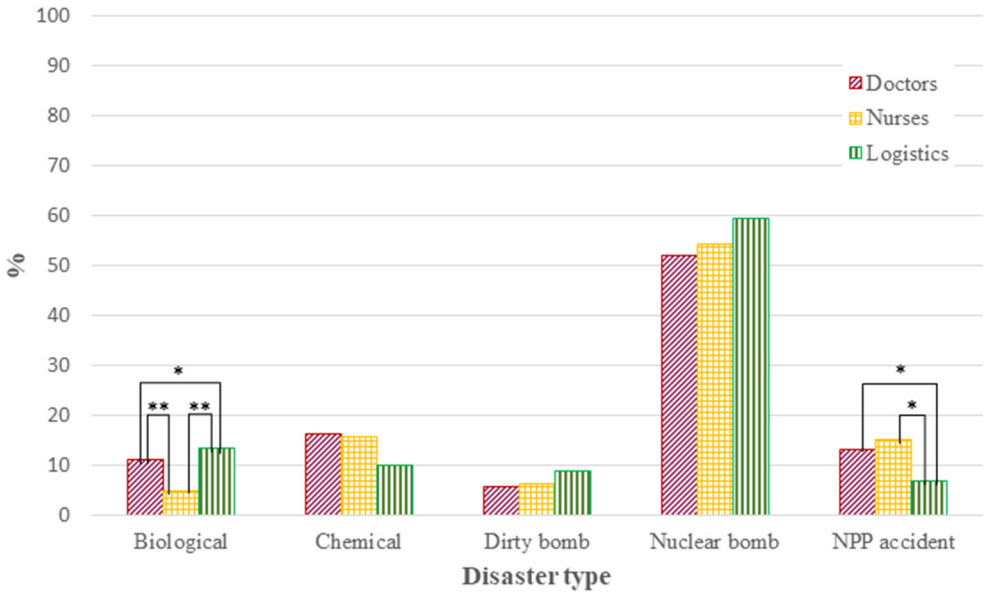


FIGURE 1 | The most important event that may prevent the respondent from coming to work. *$p < 0.05$, **$p < 0.01$. NPP indicates nuclear power plant. Chart showing response to Question 1.

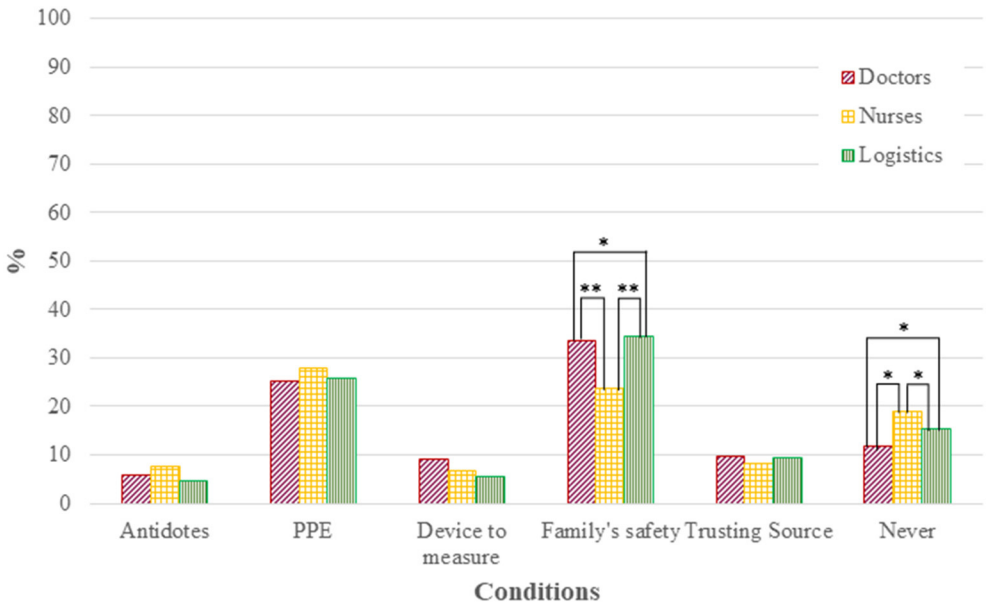


FIGURE 2 | Conditions for willingness to come to work in the event of a nuclear detonation. *$p < 0.05$, **$p < 0.01$. PPE ndicates personal protective equipment. Chart showing response to Question 4.

differences observed in univariate analysis were diminished on binary logistic regression analysis. All occupations preferred to work at the hospital they belonged to rather than at the disaster site under the possibility of radio-nuclear contamination (**Supplementary Figure 2**).

The results of familiarity with the disaster medical response team are shown in **Figure 3**. There were significant differences among the occupations regarding familiarity, and nurses were less familiar with the disaster response team than other occupations ($p < 0.01$) per univariate analysis. After binary logistic regression analysis, sex was the only influencing factor on familiarity ($p = 0.002$, OR 1.796 [1.244–2.593]).

The highest accuracy rate about the respondents' knowledge was obtained on the disaster team present in Japan for all occupations, from 79.2, 83.0, and 86.5% among nurses, logistics personnel, and doctors, respectively (**Figure 4**; Question 7).

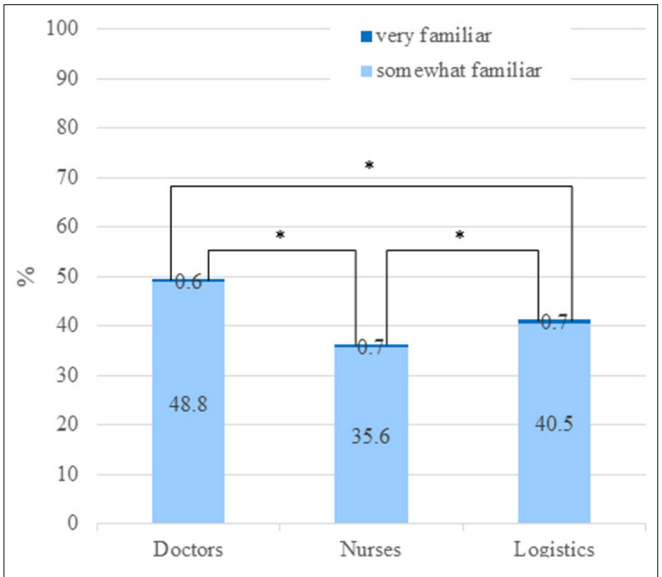


FIGURE 3 | Familiarity with disaster response teams. *$p < 0.001$. Chart showing response to Question 6.

About half of all respondents provided accurate responses about decontamination procedures needed for patients with trauma emergencies or burn injuries under the situation of a nuclear detonation (Question 12). However, the accuracy rates for the other questions were extremely low. There were significant differences in accuracy rate among occupations when the respondents were required to select the highest priority patient who needed treatment (Question 5; $p < 0.01$), and about the number of healthcare providers who were put at risk by treating patients contaminated with radiological material in all radio-nuclear events since World War II (Question 10; $p < 0.01$) per univariate analysis. Doctors as occupation tended to influence the accuracy rate for Question 5 ($p = 0.062$, OR 2.280 [0.959–2.725]) and nurses as occupation influenced the accuracy rate for Question 10 ($p = 0.007$ OR 0.092 [0.016–0.529]) on binary logistic regression analysis. The accuracy rates of responses on proper PPE (Question 13) and internal exposure (Question 14) were very low, but no significant differences occurred among occupation groups.

DISCUSSION

We conducted a questionnaire survey of participants in the Japan DMAT training course. Our analysis revealed some differences in respondents' awareness and knowledge by occupation.

All occupations were unwilling to work during nuclear bomb explosions. In situations of radiological and nuclear events, family safety and availability of appropriate PPE were the important conditions for respondents to attend work. Some respondents never intended to engage in radiological and nuclear events even if these conditions were fulfilled. Male respondents were more familiar with the disaster medical response team, and there were no significant differences among occupations after adjusting for year of birth, sex, and radiation/nuclear experience. The occupation tended to influence the accuracy rate of some questions that required knowledge in this study. Background of the occupations might be some of the reasons for their accuracy of knowledge. This study could not demonstrate relevance between the knowledge and willingness and risk perception because few questions required straight answers. In a cross-sectional online questionnaire survey of nuclear medicine technologists, Van Dyke et al. reported that attending radiological preparedness training in the last 5 years was significantly associated with increased willingness to respond to radiological and nuclear events (8). Sheikh et al. conducted a cross-sectional online survey of emergency medicine residents and their faculty; they found that physicians who had received training were significantly more knowledgeable and felt significantly more comfortable in caring for victims, performing decontamination procedures, diagnosing and managing acute radiation syndrome and internal contamination, and using detection equipment in radiological disasters (9). The respondents in this study comprised doctors, nurses, and logistic personnel in various specialties, and a low rate of them had experience in the radiation/nuclear science field. Moreover, these respondents answered the questionnaire during disaster medical training courses, and their awareness and willingness of radiological and nuclear events might be improved. It demands caution to compare the results of this study with those of other previous studies because the backgrounds of subjects and research methods were different. Nevertheless, periodic training and knowledge updates are needed to increase the willingness of medical staff to respond to radiological and nuclear events.

There was a similar tendency of awareness for a biological disaster such as a pandemic to a radiological and nuclear event. In the recent COVID-19 pandemic, several survey results revealed that approximately 61–93% of nurses were willing to participate in the care of patients with COVID-19 (21, 22). The safety of family and oneself, training, communication, and compensation are the major concerns for healthcare workers to attend work under the COVID-19 and other pandemic situations (21–24). These tendencies are consistent with the results of our survey.

The accuracy rate for some questions about respondents' knowledge was low in this survey. A few respondents answered practical questions correctly, such as determining treatment priority (Question 5), selecting proper PPE (Question 13), and treating trauma patients with internal radioactive contamination (Question 14). In addition, respondents rarely chose the correct answer for the question on historical knowledge about the number of healthcare providers who were put at risk by treating contaminated patients in all radio-nuclear events since World War II (Question 10). In particular, incorrect responses tended to be over-protective and over-fearful, such as selecting a higher level of PPE (Question 13), indicating higher perception in treating patients with internal radioactive contamination (Question 14), and estimating a larger number of healthcare providers who were put at risk while engaging in radiological and nuclear events (Question 10). There were differences

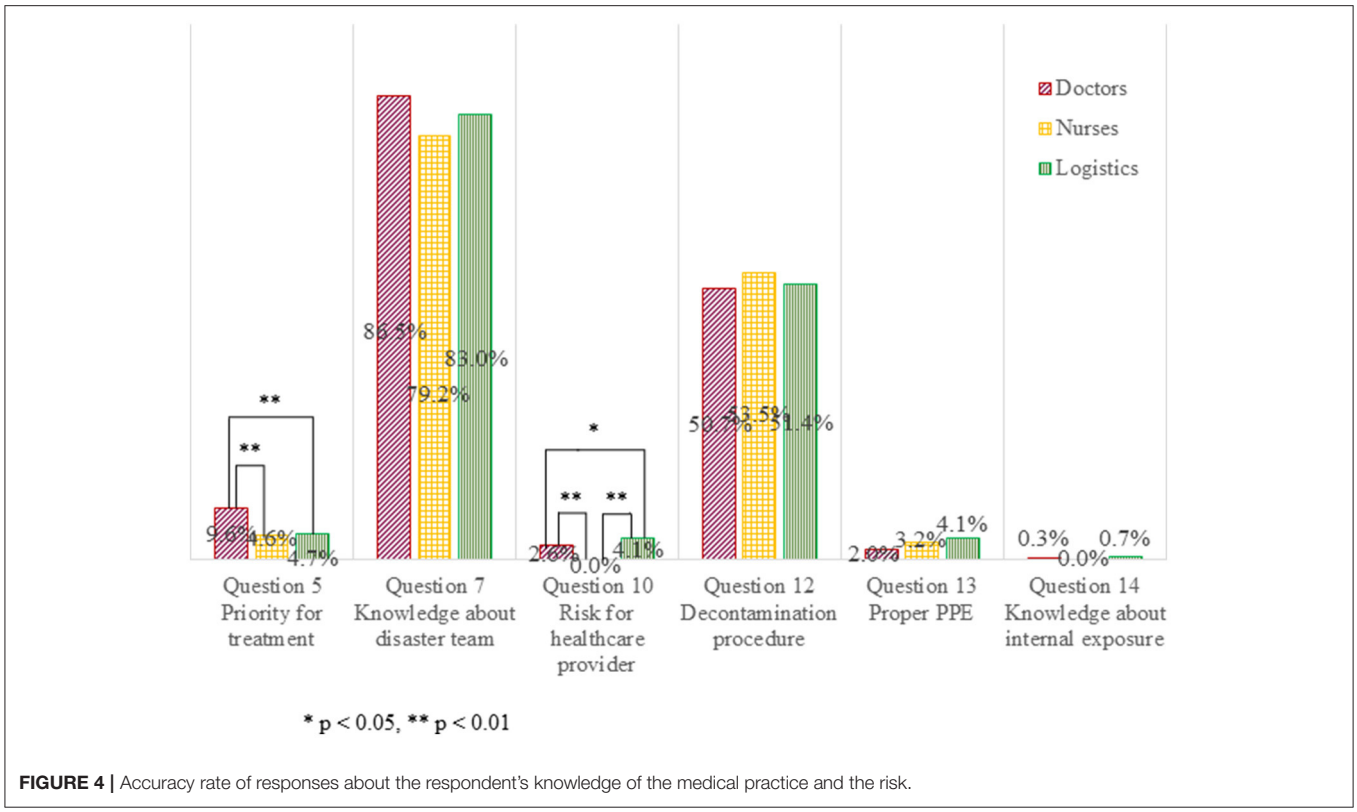


FIGURE 4 | Accuracy rate of responses about the respondent's knowledge of the medical practice and the risk.

among occupations in the accuracy rates for Questions 5 and 10, although the accuracy rate was low in all occupations. Dallas et al. suggested that Japanese respondents (61%) were much more likely to state that they did not know what type of PPE was needed for radioactive contamination than American respondents (15%) (18). Likewise, for the question about the perception of their risk in treating patients with internal radioactive contamination, an overwhelming majority of Japanese respondents indicated that they did not know, and they tended to estimate a higher risk of radioactive exposure (18). These misconceptions might be attributed to Japanese people's fearfulness regarding radiological and nuclear events based on the experiences of the Fukushima nuclear power plant accident (1) or knowledge of the history of nuclear bombings in Japan (16). Therefore, a training program for such disasters is needed to provide precise knowledge and eliminate anxiety.

Education on disasters involving radiological and nuclear events or CBRNE disasters is a pressing issue. A previous study by Sheikh et al. (9) indicated that respondents preferred packaged educational materials, classroom teaching at the workplace, drills, and case-based scenarios rather than online training and classroom teaching at a location other than the workplace. They also suggested that knowledge gaps in these areas could be due to reasons such as unappealing training formats, incomplete or limited availability of radiation-response training, or lack of opportunity for hands-on training with radiation detectors. Blumenthal et al. proposed a training strategy with members of the healthcare delivery system classified into four tiers, with tasks identified for each tier, along with the radiation-relevant knowledge needed to perform these tasks (10). This strategy is similar to that of the Japan DMAT training course, which includes separate programs by occupation (doctors, nurses, and logistics personnel) (19). It is controversial, and more investigations are expected to determine which type of training course is better to achieve a high educational effect. However, the separate program for each group divided by background or experience might elevate the motivation and comprehension level.

Both medical and technical knowledge (toxicology, biology, and radiology) are needed to engage CBRNE disaster events as medical team members. Our research suggests that background knowledge may be different between occupations. Therefore, it is reasonable to prepare separate training programs for each occupation, to improve the knowledge level of each.

The present survey had some limitations. First, it was a self-report questionnaire survey. However, the questionnaire contained questions that required the respondents to select clear distinctive alternatives that were specific, unlike questionnaires with responses on a Likert scale where the alternatives are based on subjectivity, making it difficult to interpret the reasons for the choice of responses. Second, the response rates of this survey were 55.8% (904/1,620) and 47.8% (774/1,620) for initial responders and those included in the final analysis, respectively. Moreover, because the paper questionnaire was distributed, it was difficult to check blanks in answer columns for each question, and 14.4% of respondents were lost to a missing indication of occupation. The online survey might be more suitable for pointing out no

answers and useful for increasing the response rate. Despite the low response rates, the 774 respondents included in the study constituted a sufficient number for the analysis. Third, since this survey targeted medical staff who underwent a disaster training course and intended to work at disaster sites, the cohort is considered a highly motivated group for disaster medicine and CBRNE events. Therefore, this cohort could be biased. It requires caution to interpret the result of this study and to compare it with previous studies because the questionnaire was distributed during the training course, and the awareness and knowledge were improved more than usual or that at baseline. Nevertheless, our subjects were the main candidates who are engaged in such disaster events, and the results of this survey are useful to modify the curricula of the current stratified type of disaster training course in Japan.

In conclusion, our survey revealed differences in levels of knowledge of radiological and nuclear events by healthcare occupation. Japanese people's fearfulness regarding radiological and nuclear events based on the experiences of the Fukushima nuclear power plant accident or knowledge of the history of nuclear bombings in Japan may explain the results of this research. The differences might be based on the educational background of each occupation. The results can be useful in the development and improvement of training courses for managing radiological and nuclear events. The development of a course that could compensate for the lack of knowledge of each healthcare worker would be beneficial.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Institutional Review Board (IRB) of the University of Texas Southwestern Medical Center. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

KO designed the study, analyzed the data and was a major contributor in writing the manuscript. TO, NK, YK, YO, and RS designed the study and revised manuscript. All authors participated in the discussion about the interpretation of data. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

We would like to thank the staff of the Japan Disaster medical assistance team (DMAT) Secretariat for their support of this study. Especially, Hisayoshi Kondo, and Yuichi Koido, Japan DMAT Secretariat, National Hospital Organization Disaster Medical Center.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2022.808148/full#supplementary-material

REFERENCES

1. Ohto H, Yasumura S, Maeda M, Kainuma H, Fujimori K, Nollet KE. From devastation to recovery and revival in the aftermath of Fukushima's nuclear power plants accident. *Asia Pac J Public Health.* (2017) 29:10S–7S. doi: 10.1177/1010539516675700
2. Hasegawa A, Tanigawa K, Ohtsuru A, Yabe H, Maeda M, Shigemura J, et al. Health effects of radiation and other health problems in the aftermath of nuclear accidents, with an emphasis on Fukushima. *Lancet.* (2015) 386:479–88. doi: 10.1016/S0140-6736(15)61106-0
3. Zablotska LB. 30 years after the Chernobyl nuclear accident: time for reflection and re-evaluation of current disaster preparedness plans. *J Urban Health.* (2016) 93:407–13. doi: 10.1007/s11524-016-0053-x
4. Kulka U, Abend M, Ainsbury E, Badie C, Barquinero JF, Barrios L, et al. RENEB—Running the European Network of biological dosimetry and physical retrospective dosimetry. *Int J Radiat Biol.* (2017) 93:2–14. doi: 10.1080/09553002.2016.1230239
5. Mortelmans LJM, Gaakeer MI, Dieltiens G, Anseeuw K, Sabbe MB. Are Dutch hospitals prepared for chemical, biological, or radionuclear incidents? A survey study. *Prehosp Disaster Med.* (2017) 32:483–91. doi: 10.1017/S1049023X17006513
6. Stevens G, Jones A, Smith G, Nelson J, Agho K, Taylor M, et al. Determinants of paramedic response readiness for CBRNE threats. *Biosecur Bioterror.* (2010) 8:193–202. doi: 10.1089/bsp.2009.0061
7. Jama TJ, Kuisma MJ. Preparedness of Finnish emergency medical services for chemical emergencies. *Prehosp Disaster Med.* (2016) 31:392–6. doi: 10.1017/S1049023X16000546
8. Van Dyke ME, McCormick LC, Bolus NE, Pevear J, Kazzi ZN. Radiological emergency preparedness: a survey of nuclear medicine technologists in the United States. *J Nucl Med Technol.* (2013) 41:223–30. doi: 10.2967/jnmt.113.124677
9. Sheikh S, McCormick LC, Pevear J, Adoff S, Walter FG, Kazzi ZN. Radiological preparedness-awareness and attitudes: a cross-sectional survey of emergency medicine residents and physicians at three academic institutions in the United States. *Clin Toxicol (Phila).* (2012) 50:34–8. doi: 10.3109/15563650.2011.637047
10. Blumenthal DJ, Bader JL, Christensen D, Koerner J, Cuellar J, Hinds S, et al. A sustainable training strategy for improving health care following a catastrophic radiological or nuclear incident. *Prehosp Disaster Med.* (2014) 29:80–6. doi: 10.1017/S1049023X1400003X
11. Coccolini F, Sartelli M, Kluger Y, Pikoulis E, Karamagioli E, Moore EE, et al. COVID-19 the showdown for mass casualty preparedness and management: the Cassandra Syndrome. *World J Emerg Surg.* (2020) 15:26.doi: 10.1186/s13017-020-00304-5
12. Aziz S, Arabi YM, Alhazzani W, Evans L, Citerio G, Fischkoff K, et al. Managing ICU surge during the COVID-19 crisis: rapid guidelines. *Intensive Care Med.* (2020) 46:1303–25. doi: 10.1007/s00134-020-06092-5
13. Goh KJ, Wong J, Tien JC, Ng SY, Duu Wen SD, Phua GC, et al. Preparing your intensive care unit for the COVID-19 pandemic: practical considerations and strategies. *Crit Care.* (2020) 24:215. doi: 10.1186/s13054-020-02916-4
14. Griffin KM, Karas MG, Ivascu NS, Lief L. Hospital preparedness for COVID-19: a practical guide from a critical care perspective. *Am J Respir Crit Care Med.* (2020) 201:1337–44. doi: 10.1164/rccm.202004-1037CP

15. Kanwar A, Heppler S, Kanwar K, Brown CK. A survey of SARS-CoV-2 preparedness among hospitals in Idaho. *Infect Control Hosp Epidemiol.* (2020) 11:1–25. doi: 10.1017/ice.2020.218
16. Clancey G, Chhem R. Hiroshima, Nagasaki, and Fukushima. *Lancet.* (2015) 386:405–6. doi: 10.1016/S0140-6736(15)61414-3
17. Information concerning nuclear power plants in Japan. *Agency for Natural Resources and Energy, Ministry of Economy, Trade and Industry website*. (2021). Available online at: http://www.enecho.meti.go.jp/category/electricity_and_gas/nuclear/001/. (accessed on December 17, 2021).
18. Dallas CE, Klein KR, Lehman T, Kodama T, Harris CA, Swienton RE. Readiness for radiological and nuclear events among emergency medical personnel. *Front Public Health.* (2017) 5:202. doi: 10.3389/fpubh.2017.00202
19. Anan H, Akasaka O, Kondo H, Nakayama S, Morino K, Homma M, et al. Experience from the great east japan earthquake response as the basis for revising the japanese disaster medical assistance team (DMAT) training program. *Disaster Med Public Health Prep.* (2014) 8:477–84. doi: 10.1017/dmp.2014.113
20. Anan H, Otomo Y, Kondo H, Homma M, Koido Y, Morino K, et al. Development of mass-casualty life support-CBRNE (MCLS-CBRNE) in Japan. *Prehosp Disaster Med.* (2016) 31:547–50. doi: 10.1017/S1049023X16000686
21. Wu B, Zhao Y, Xu D, Wang Y, Niu N, Zhang M, et al. Factors associated with nurses' willingness to participate in care of patients with COVID-19: a survey in China. *J Nurs Manag.* (2020) 28:1704–12. doi: 10.1111/jonm.13126
22. Lord H, Loveday C, Moxham L, Fernandez R. Effective communication is key to intensive care nurses' willingness to provide nursing care amidst the COVID-19 pandemic. *Intensive Crit Care Nurs.* (2021) 62:102946. doi: 10.1016/j.iccn.2020.102946
23. Imai H. Trust is a key factor in the willingness of health professionals to work during the COVID-19 outbreak: experience from the H1N1 pandemic in Japan 2009. *Psychiatry Clin Neurosci.* (2020) 74:329–30. doi: 10.1111/pcn.12995
24. Almaghrabi RH, Alfaraidi HA, Al Hebshi WA, Albaadani MM. Healthcare workers experience in dealing with coronavirus (COVID-19) pandemic. *Saudi Med J.* (2020) 41:657–60. doi: 10.15537/smj.2020.6.25101

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

frontiers | Frontiers in Psychology

ORIGINAL RESEARCH
published: 10 August 2022
doi: 10.3389/fpsyg.2022.818422

Employees Perception of Organizational Crises and Their Reactions to Them – A Norwegian Organizational Case Study

Jarle Løwe Sørensen[1], Jamie Ranse[2,3], Lesley Gray[4,5], Amir Khorram-Manesh[6,7], Krzysztof Goniewicz[8] and Attila J. Hertelendy[9,10,11]*

[1]Department of Business, History and Social Sciences, USN School of Business, University of South-Eastern Norway, Kongsberg, Norway, [2]School of Nursing and Midwifery, Griffith University, Gold Coast, QLD, Australia, [3]Department of Emergency Medicine, Gold Coast Health, Gold Coast, QLD, Australia, [4]Department of Primary Health Care and General Practice, University of Otago, Wellington, New Zealand, [5]Joint Centre for Disaster Research, Massey University, Wellington, New Zealand, [6]Department of Surgery, Institute of Clinical Sciences, Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden, [7]Gothenburg Emergency Medicine Research Group (GEMREG), Sahlgrenska Academy, Gothenburg University, Gothenburg, Sweden, [8]Department of Security, Polish Air Force University, Dęblin, Poland, [9]Department of Emergency Medicine, Fellowship in Disaster Medicine, Beth Israel Deaconess Medical Center and Harvard Medical School, Boston, MA, United States, [10]Department of Emergency Medicine, Harvard Medical School, Boston, MA, United States, [11]Department of Information Systems and Business Analytics, College of Business, Florida International University, Miami, FL, United States

OPEN ACCESS

Edited by:
Matteo Cristofaro, University of Rome Tor Vergata, Italy

Reviewed by:
Lucia Velotti, John Jay College of Criminal Justice, United States
Bahtiar Mohamad, Universiti Utara Malaysia, Malaysia

****Correspondence:***
Jarle Løwe Sørensen
jarle.sorensen@usn.no

Specialty section:
This article was submitted to Organizational Psychology, a section of the journal Frontiers in Psychology

Received: *19 November 2021*
Accepted: *14 June 2022*
Published: *10 August 2022*

Citation:
Sørensen JL, Ranse J, Gray L, Khorram-Manesh A, Goniewicz K and Hertelendy AJ (2022) Employees Perception of Organizational Crises and Their Reactions to Them – A Norwegian Organizational Case Study. Front. Psychol. 13:818422. doi: 10.3389/fpsyg.2022.818422

Organizational sensemaking is crucial for resource planning and crisis management since facing complex strategic problems that exceed their capacity and ability, such as crises, forces organizations to engage in inter-organizational collaboration, which leads to obtaining individual and diverse perspectives to comprehend the issues and find solutions. This online qualitative survey study examines how Norwegian Sea Rescue Society employees perceived the concept of an organizational crisis and how they sensed their co-workers react to it. The scope was the ongoing COVID-19 pandemic, a global event affecting all countries and organizations and responding similarly globally. Data were collected during the Fall of 2020. The instrument of choice was the Internal Crisis Management and Crisis Communication survey (ICMCC). The results showed that the overall sample strongly believed in their organization's overall resilience level. However, a somewhat vague understanding of roles and responsibilities in a crisis where detected, together with some signs of informal communication, rumor spreading, misunderstanding, frustration, and insecurity. This study contributes to the academic field of organizational research, hence crisis management and sensemaking, and could be valuable to managers and decision-makers across sectors. Increased knowledge about how employees react to a crisis may help optimize internal crisis management planning and utilize robust mitigation and response strategies.

Keywords: crisis communication, crisis management, organization, organizational psychology, sensemaking

INTRODUCTION

On March 12, 2020, the Norwegian Institute of Public Health (2020) reported that 621 individuals had tested positive for the SARS-CoV-2 (COVID-19) coronavirus disease. In response, the Norwegian Government introduced the most substantial and intrusive control measures in Norway since World War 2. Kindergartens, schools, and higher education institutions were closed, cultural, sports events and organized activities were prohibited, and health professionals who work in patient care were forbidden to leave the country. Additionally, entry quarantine to Norway and a ban on staying on one's leisure property were introduced (Norwegian Government, 2020). One year later, COVID-19 has taken its toll on both societies and individuals. The virus has also brought several unexpected variables for organizations, which many people had not planned for or were equipped to handle. Against this backdrop, we extend Bailey and Breslin's (2021) argument that an organization's ability to mitigate and respond to major crises like the COVID-19 pandemic is closely linked with the concept of resilience. Here, organizational resilience relates to an organization's capacity to learn and reflect from past incidents, show flexibility, adapt to new situations, and take advantage of- and utilize existing resources (Steen and Morsut, 2020). Considering that nations have always struggled with and fought against infectious diseases, it could be assumed that the ability to mitigate from- and respond to pandemics has continuously increased, but as Klein (2021) pointed out, more knowledge alone has not always shown enough. Imposed measures must also be explained and put in the proper social perspective. The ongoing pandemic has taught us that a crisis may affect an organization's external and internal life. Therefore, it is in an organization essential to build and join together both inner and outer resilience in crisis management. A paucity of literature reviews the dynamics of internal crisis management (Frandsen and Johansen, 2011; Heide and Simonsson, 2015; Adamu and Mohamad, 2019).

Organizational sensemaking is crucial for resource planning and crisis management. Previous publications indicate that when organizations face complex strategic problems which exceed their capacity and ability, such as diverse crises, they search for inter-organizational collaboration, which enables the accumulation of staff individual and diverse perspectives, in the hope of understanding the depth and nature of the issues to find proper solutions (Seidl and Werle, 2018; Tan et al., 2020). This online qualitative survey study examines how Norwegian Sea Rescue Society employees perceived the concept of an organizational crisis and how they sensed their co-workers react to it. The scope was the ongoing COVID-19 pandemic, a global event affecting all countries and organizations and responding similarly globally. As a contribution to organizational research, this online-survey-based case study, from a sensemaking perspective, aimed to examine how Norwegian Sea Rescue Society employees perceived the concept of an organizational crisis (the COVID-19 pandemic) and how they sense their co-workers reacted to it. Karl Weick's theory on sensemaking (Weick, 1995, 2010, 2012, 2015) was deemed most appropriate as it focuses on crises and situations where organizational sensemaking is challenged or breaks down (Johansen et al., 2012).

As the sensemaking concept, today can be described more as a general notion than a unified term; we see the need to narrow down the scope in this study and have chosen Maitlis and Christianson's (2014) four recurring sensemaking themes as the starting point for our discussion. The COVID-19 pandemic was proven to affect all nations and organizations which responded to its progression and impacts somewhat similarly and globally (Khorram-Manesh et al., 2020). We thus consider this study to have relevant transfer value across sectors. Increased knowledge about how individuals make sense of- and react to organizational crises would contribute to organizational research and sensemaking. This online qualitative survey study showed that the overall sample strongly believed in their organization's overall resilience level. However, a somewhat vague understanding of roles and responsibilities in a crisis where detected, together with some signs of informal communication, rumor spreading, misunderstanding, frustration, and insecurity. Our research is based on the frameworks of an earlier Danish study on internal crisis management and communication. Internal response, also known as an organizational response or business continuity management, focuses on an organization's inner dynamics to a crisis, hence its overall approach and strategic instruments (Johansen et al., 2012). We consider addressing the internal perspective especially relevant as last decade, CM and CC research have, in large, focused on the external dimensions of the crisis, hence, how to restore from a possible reputation or image damage. Thus, research on the internal life in crisis from a sensemaking perspective is to be considered limited (Frandsen and Johansen, 2011).

BACKGROUND

Crisis

A crisis can be described as an overwhelming situation that overstrains available capacities and resources (Van Wart and Kapucu, 2011; Sriharan et al., 2022). A crisis is more transboundary than everyday emergencies and often exceeds natural or manmade geographical, organizational or administrative borders (Ansell et al., 2010). Despite growing attention to the crisis, it has been proven difficult to establish a consensus about a unified crisis definition (Wolbers et al., 2021). Bundy et al. (2017) point out that research on crises and their management remains fragmented. The organizational crisis literature is somewhat cofounded by several and sometimes conflicting explanations and definitions (Kovoor-Misra et al., 2001), and there are still many theoretical, practical, and conceptual challenges that need resolving (Lalonde and Roux-Dufort, 2013). According to Roux-Dufort and Lalonde (2013), the diversity of conceptualizations indicates that we are faced with a wandering phenomenon. Upon examining the development of- and knowledge gaps in business and management research on organizational resilience, Linnenluecke (2017) found in her review that the research on resilience has developed into five main streams: "(1) organizational responses to external threats,

(2) organizational reliability, (3) employee strengths, (4) the adaptability of business models or (5) design principles that reduce supply chain vulnerabilities and disruptions" (p. 4). The review concluded that many organizations, as a result, will face unpreparedness when a crisis strike if they do not increase their overall capacities and their knowledge about the discussion-making process and resilience planning.

One type of crisis, organizational crisis, an area of interest in this study, is defined as a low-probability, high-impact event that threatens the organization's sustainability (Pearson and Clair, 1998; Kim, 2018). It can be caused by natural and manmade hazards and pose internal and external challenges (Winston, 2019). Other earlier sources, such as Nystrom and Starbuck (2015), viewed crises as a threat to organizational development, while Milburn et al. (1983) saw them both as a threat and an opportunity. While Weick (1988) argued that a crisis was a low probability event, others like Smart and Vertinsky (1984) reasoned that it could be high and low. Whereas Pearson and Mitroff (1993) claimed that the element of surprise was a hallmark in crisis, Kerchner and Schuster (1982), on the contrary, argued that they were somewhat predictable. Relevant to this study, and as pointed out by Boin and t Hart (2022), a crisis could also be seen as a "*catalyst for change*" (p. 13). The justification argument stems from what Barton (1970) referred to as "collective stress," which, summarized by Boin and t Hart, helps relieve and wash away existing and often tradition-based institutional myths and patterns. New thinking may be beneficial but also challenging for organizations that have a markedly mechanistic (Burns and Stalker, 1961) approach to crisis management, where the action logic is focused on a linear, rigid, and fixed hierarchical system.

From an organizational viewpoint, mitigating and preparing for crises has become increasingly tricky as 21st-century organizations face ever-changing technological, communicative and cultural challenges (Aljuhmani and Emeagwali, 2017). Crisis survival is thus much dependent on the organization's overall level of resilience (Teo et al., 2017). Resilience is the ability to react (Williams et al., 2017) and recover from damaging events or blows (Longstaff, 2005). Hwang and Lichtenthal (2000) argued that organizations could be subject to two main types of crisis; abrupt or cumulative, where the abrupt is a one-time event that occurs suddenly and challenges the state of normal, while the cumulative builds up gradually over time. Following the latter, an organizational crisis may be viewed as a three-stage multi-disciplinary process consisting of pre-crisis, crisis, and post-crisis (Johansen and Frandsen, 2007). The organization identifies and takes strategical and tactical mitigation measures during this process, responds to the crises, and restores a normal state (Coombs and Holladay, 2014; Zamoum and Gorpe, 2018). While such a multi-disciplinary approach to organizational crisis handling is embraced by several scholars (Smart and Vertinsky, 1984; Weick, 1988; Kovoor-Misra et al., 2001), it has also been criticized for nurturing up under and contributing to lacking unification within the field of organizational crisis research (Pearson and Clair, 1998).

Managing Crisis

Compared to managing routine-based daily operations, a crisis (also known as a disaster) can be quite challenging and stressful (Peyravi et al., 2021). Stated reasons include that crisis occurs with less regularity and often is more disorganized and resource-overwhelming (Ansell et al., 2010; Sørensen, 2017). It also presents stakeholders with higher uncertainty levels (Mitroff et al., 1987), combined with pressure to make quick and effective decisions within short time frames, often based on little or poorly validated information (Lu and Xue, 2016). Lastly, as Van Wart and Kapucu (2011) pointed out, there is an additional inconsistency and notable difference in how the crisis concept is viewed across public and private sectors. While public organizations tend to associate the main task of managing a crisis with facilitating and allocating resources to mitigate, prepare, and respond to expected and unexpected manmade or natural hazards, the NGO sector includes all untoward events and uses the crisis term more broadly. On that note, successful organizational crisis handling depends not just on effective management, structured planning and rapid decision-making. An organization's success relies just as much on its nature (Gilpin and Murphy, 2008) and its relationship with its employees (Frandsen and Johansen, 2011).

Since the 1960s, extensive organizational hierarchies and excessive bureaucracies have been considered ineffective (Downs, 1967). Such ways of organizing are especially true in crises. Findings show that organizations that have implemented long vertical structures often are challenged, as the vertical structure may hinder effective decision-making and often needed information flow (Berlin and Carlström, 2013). As employees can positively or negatively impact the outcome of a crisis, they should always be considered an essential resource (Frandsen and Johansen, 2011).

Everyday users of systems and procedures are often the ones that are in an immediate position to notice early warning crisis signs and detect discrepancies. Therefore, it is an essential management task to ensure that employees develop their crisis perspective and awareness to contribute to their organization's overall crisis management (Heide and Simonsson, 2015). As argued by Weick and Ashford (2001), employees who are empowered are, in crises, not only able to act through established and rehearsed procedures; they are also capable of improvising and implementing alternative solutions. To be able to improvise and implement, there first needs to be an effort to understand connections. Such ability to turn unclear and often unexpected incidents into explicit and comprehensive situations is called sensemaking (Weick et al., 2005).

Making Sense

In organizations, sensemaking serves as a plausible image and rationale for behavior. When stakeholders encounter ambiguous or uncertain situations, they will seek to "make sense" of them and act by examining and using existing organizational and environmental cues (Weick, 1995; Weick and Ashford, 2001; Weick et al., 2005; Maitlis and Christianson, 2014). Sensemaking is thus more about situational interpretation and action interplay than an assessment of choice (Laroche, 1995).

According to a 2014 review study by Maitlis and Christianson (2014), the "sensemaking language" was introduced in the literature at the beginning of the twentieth century in works by, e.g., Dewey (1922) and James (1890), but it was first when Karl Weick introduced the concept of organizational sensemaking in his 1969 book "The Social Psychology of Organizing" sensemaking became a critical topic within organizational research (Weick, 1969). At the time, the book contributed to an ongoing debate on whether ecological changes in an organization's environment, among others, create modifications that engage the attention of relevant actors, resulting in recursive selections and retentions. Later, Weick (1995) described how he viewed sensemaking as a process that is "is (i) grounded in identity construction, (ii) retrospective, (iii) enactive of sensible environments, (iv) social, (v) ongoing, (vi) focused on and extracted cues and (vii) driven by plausibility rather than accuracy" (Magnussen et al., 2018, p. 247). Then, in 2001, he provided a further holistic understanding of the phenomenon by explaining the four opinion capture process stages: (1) action, (2) interaction, (3) social commitment, and (4) committed interpretation (Magnussen et al., 2018).

The notion of sensemaking may be viewed from several different perspectives. Individual sensemaking processes occur when individuals engage in retrospective and prospective thinking to construct an interpretation of reality (Sonenshein, 2010). For example, when faced with an unfolding personal crisis, a person may engage in sensemaking about their future when a situation shatters their existing personal and worldly assumptions (Keesee et al., 2008; Park, 2010). Such processes are also relevant in the study of working environments and professional interplay, examples being Weick's known studies of the Bhopal (Weick, 2010), Mann Gulch (Weick, 1993) and Tenerife (Weick, 1990) disasters, which later have been regarded as pioneer studies within the crisis sensemaking field (Johansen et al., 2012).

The way individuals first construct meaning is influenced by several factors and levels, including their internal environment, culture, background, and identity (Prior et al., 2018). Weick (1988) argued that when people act, they initially bring constructs into existence that they set into action. In an attempt to make sense, people, through mental modeling processes, notice and bracket down the environment to identify new cues that they again contemporaneously validate (Weick et al., 2005). Cristofaro (2020) argued in his proposed *Affective-Cognitive Theory of management decisions* that when sense makers feel a positive, negative or even mixed affective state, they are driven to search for explanatory cues. However, the cues themselves are not a final solution to the sensemaking process but rather pieces of information, which the sensemaker uses to form a schema already shaped and influenced by existing "elicited affective states" (p. 9).

In later work-life studies, Christianson et al. (2009), which studied the 2003 collapse of the roof of the Baltimore & Ohio (B&O) Railroad Museum Roundhouse, found, for example, that employees' sensemaking was triggered upon trying to understand and cope with the future of their museum and whether the collapse and destruction were to be understood as a permanent, temporary setback. In a Norwegian study on whether sensemaking processes may influence emergency call center dispatchers' decision-making when dealing with maritime crises, Magnussen et al. (2018) found that the dispatchers` past professional experiences influenced the sensemaking processes that took place before the actual decision-making, and thus did not always result in optimal outcomes. In sum, knowledge about sensemaking enables organizations to mitigate and act when faced with a crisis (Weick et al., 2005). It provides stakeholders with a structured process of dealing with uncertainty (Weick, 1995) and explains mental reality models (Namvar et al., 2018), contributing to informed decision-making. On that note, traditional sensemaking models have been criticized for not fully considering the role of emotions in individuals and organizations (Maitlis et al., 2013).

Today, sensemaking can be viewed more as a general notion than a unified term. According to Maitlis and Christianson (2014), the many different definitions expose the many ontological assumptions (Louis, 1980; Starbuck and Milliken, 1988; Gephart, 1993; Weick, 1995) that contribute to defining and further developing sensemaking theory. However, according to the authors, it can still be argued that there are four recurring themes, which will serve as the starting point for our further discussion. First, sensemaking should be viewed as a dynamic process where the focus is on transience over constancy (Hernes and Maitlis, 2012). Second, sensemaking seems to be triggered, especially when stakeholders face unanticipated events (Maitlis, 2005). Third, despite being a general notion, sensemaking should be viewed as a social construct, as organizations and individuals make sense based on their existing thoughts and feelings, thus already being affected by the "actual, imagined, or implied presence of others "(Allport and James, 1985, p. 3, cited in Weick, 1995, p. 39 and in Maitlis and Christianson, 2014, p. 66). Finally, a fourth critical element is the fact that when people take action to make sense of a situation, it, in turn, affects the very environment they want to understand, thus creating "rational accounts of the world that enable action" (Maitlis, 2005, p. 21, cited in Maitlis and Christianson, 2014, p. 66).

MATERIALS AND METHODS

Design

This research is a simple quantitative design, using an online survey of employees of the Norwegian Sea Rescue Society (RS).

Population and Sample - The Case of the Norwegian Sea Rescue Society

The population for this research included the 1,600 permanent and volunteer rescue workers of The Norwegian Sea Rescue Society (Redningsselskapet, RS.) Founded in 1891, the RS is Norway's most prominent humanitarian maritime search and rescue (SAR) organization. The Redningsselskapet organizes 52 rescue vessels, four ambulance vessels and other support vessels. In addition to national duties, the organization participates in several international projects and partnerships (Redningsselskapet, 2020). RS was deemed

a relevant study sample based on its long-standing SAR traditions, organizational size, and international commitment.

Further, the organization's response to the COVID-19 Coronavirus was considered relevant as a case study since operational insecurity, infection control requirements, and human resource challenges did pose administrative and managerial challenges to the organization. A sample size calculation was undertaken using G*Power, a free-to-use statistical software package (Faul et al., 2009). The sample size calculation was set with a statistical power of 0.80 with an alpha significance level of 0.05, and an effect size of 0.3 (Cohen, 2013). The appropriate sample size was calculated to be 82.

Data Collection

Instead of 82 participants, 365 possible participants were sent an e-mail invitation to complete an online survey *via* the RS Human Resource department. The invitation described the study, its purpose and a hyperlink to the survey. Furthermore, contact information for the researchers, along with RS's approval, was enclosed. One e-mail reminder was sent to potential participants, and data collection closed 16 days after the initial e-mail.

The survey was based on the Danish-developed Internal Crisis Management and Crisis Communication survey (ICMCC). This survey was designed to measure organizational participants' perceived internal crisis management and communication levels. The ICMCC survey was developed as part of the Danish research project "Internal Crisis Management and Crisis Communication in Danish Organizations" (2011–2014), which was financed by the Danish Council for Independent Research/ Social Sciences (Johansen et al., 2012). The theoretical framework of the ICMCC was built around crisis management, sensemaking and internal stakeholder theory, thus relevant to this study. The ICMCC's homogeneity had earlier been tested by calculating Chronbach's alpha. The test calculated an alpha value of 0.76, which was considered satisfactory according to Altman (1990).

The survey included two sections. Demographic information was collected, including the participant's age, gender, highest educational level, years of working experience, whether they have crisis management/communication as part of their job description, and whether they had received crisis management/ communication training collected. Secondly, participants were asked to pick one or more crisis definitions from a list of four predetermined from the original ICMCC survey. Then, participants were asked to rank how they perceived other employees react to crises against 18 different reaction types, using a five-point Likert scale ranging from 1 = 'strongly disagree' to 5 = 'strongly agree.'

Data Analysis

After data collection, data were cleaned and imported to Statistical Package for the Social Sciences (IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp). First, demographical data were analyzed using frequencies and means of central tendency for descriptive purposes. Second, the sample's crisis perception and reactions to the crises outlined in the ICMCC survey were analyzed. Again, frequencies and central tendency were used to indicate observation averages and identify the dataset's dispersion (Barde and Barde, 2012).

Protection of Human Participants

To ensure that the study was performed in accordance with ethical research standards, ethical approval was obtained from the Norwegian Center for Research Data (NSD) before data collection (reference number 672295). Additionally, permission was obtained from the RS to conduct this research. Participant volunteerism was emphasized in the initial invitation to participants and during the survey. To ensure further voluntary participation, the participants answered an "I wish to participate in this study" question with a yes/no alternative as the first survey question. Additionally, to ensure anonymity, age and years of working experience, answer options were presented in predefined groupings.

FINDINGS

Demographics

A total of 73 ($N = 73$) persons agreed to participate in this study. The response rate was 20%. That gave an overall statistical power of 0.75. Seventy-seven percent of the respondents were males, and 23% were females. Most participants belonged to the 50–59 age group (33.5%) or the 40–49 (33.0%). Further, 19% belonged to the 30–39 group, 5.5% to the 20–29, and 11.0% to the 60–69 age group. Over half (57.8%) stated four years of higher education as their highest level, while 18.3% listed a high-school level. Twenty-two percent had more than four years of higher education, while one individual listed a doctoral educational level. Years of RS working experience varied from under one to 15+. The distributions were as followed: 0–1 (10.7%), 1–5 (25.3%), 6–10 (36.0%), 11–15 (13.3%), and 15+ (14.7%). Close to half (48.5%) either strongly or somewhat agreed that they had crisis management as part of their function. Thirty-four point 5% either strongly or somewhat disagreed. Over half (55.4%) strongly disagreed that they had received crisis management/communication training, while 9.5% somewhat disagreed. Thirty-one point 1% either strongly or somewhat agreed (**Table 1**).

Employee's Pattern Perception of Crisis

Of the four crisis pattern descriptions provided (**Table 2**), over half (63.6%) supported the claim that a crisis is an incident involving damage to stakeholders (customers, members, employees, volunteers, etc.). Fifty-four point 5% supported the assertion that an incident put parts of the organization out of operation within a short period. Fewer of the sample population perceived that a crisis threatens the entire organization's existing foundation (22.1%) or is poorly handled by the organization's management (10.4%).

Perceived Co-worker's Reaction to Crises

Upon being asked how the participants perceived that their co-workers react to crises (**Table 3**), most perceived they would

TABLE 1 | Demographics.

Gender	%	Age group	%	Years of RS experience	%	Educational level	%
Male	77	20–29	5.5	0–1	10.7	High-school	18.3
Female	23	30–39	19.0	1–5	23.3	Higher (4 years)	57.8
		40–49	33.0	6–10	36.0	Higher (4+ years)	22.5
		50–59	33.5	11–15	13.3	Doctoral level	1.4
		60–69	11.0	15+	14.7		

N = 73.

TABLE 2 | Employee's pattern perception of crisis (from high to low).

Crisis perception	%
An incident involving damage to stakeholders (customers, members, employees, volunteers, etc.)	63.6
An incident that within a short time-period put parts of the organization out of operation	54.5
An incident that threatens the entire organization's existing foundation	22.1
An incident that is poorly handled by the management of the organization	10.4

N = 73.

TABLE 3 | Perceived reactions to crises.

Text	Mean	SD
Need more information	4.32	0.92
More informal communication	2.90	1.16
Insecurity	2.89	1.20
Frustration	2.86	1.23
Spread rumors	2.75	1.28
Feel sorrow	2.63	0.99
Misunderstand the situation	2.48	1.08
Scared	2.29	1.33
Become silent	2.25	1.04
Community	2.13	1.29
Loss of motivation	1.83	1.08
Leaving the organization	1.80	1.01
Loss of confidence	1.79	1.06
Feel betrayed	1.77	0.95
Feel ashamed	1.73	0.95
Passive	1.70	0.99
Identification	1.69	0.89
Panic	1.44	0.77

out a need for more information ($M = 4$ 0.32, SD = 0.92). Next followed a sense that several would produce more informal communication ($M = 2.90$, SD = 1.16), feel insecure ($M = 2.89$, SD = 1.20), and frustrated ($M = 2.86$, SD = 1.23). On the other side, as seen in the table, few perceived that their co-workers would become passive ($M = 1.70$, SD = 0.99) or panic ($M = 1.44$. SD = 0.77). Further, the findings showed that only a minory perceived that their colleagues would lose motivation ($M = 1.83$, SD = 1.08), leave the organization ($M = 1.80$, SD = 1.01), lose confidence ($M = 1.79$, SD = 1.06), or feel ashamed ($M = 1.73$, SD = 0.95).

DISCUSSION

First, by taking as a starting point that sensemaking involves a dynamic process where the focus is on transience over constancy (Hernes and Maitlis, 2012), it flows nicely together with the notion that a crisis, here the COVID-19 pandemic, in its nature, is a rare, overwhelming and abnormal occurrence. Most participants perceived the pandemic as an incident involving damage to stakeholders (customers, members, employees, volunteers, etc.). That over half also defined the ongoing corona crisis as an incident that within a short time put parts of the organization out of operation; it also aligned well with Pearson and Clair's (1998) definition of an organizational crisis, thus being a low-probability, high-impact event. Based on the assumption that the sample responded to the survey questions built on how they perceived the Norwegian Sea Rescue Society had responded to the COVID-19 outbreak during the first three quarters of 2020, only 10.4% reported that they associated a crisis with an incident that was poorly handled by the management. Despite that managing crisis can be quite challenging and stressful compared to standard routine procedures, the findings indicate strong confidence in RS's ability to handle a crisis. Combined, it indicates trust in management and widespread belief in organizational resilience, that RS is an organization that internally can handle both abrupt and cumulative incidents (Hwang and Lichtenthal, 2000), which both are represented in the ongoing pandemic. Such findings are positive in light of Gilpin and Murphy's (2008) earlier discussed argument of how an organization's success relies on its nature and its relationship to its workers (Frandsen and Johansen, 2011). Findings signal a highly empowered employee group with a high degree of crisis awareness (Weick and Ashford, 2001), who can turn unclear and often unexpected incidents into understandable and tangible situations (Weick et al., 2005).

Second, results align with the assumption that sensemaking seems to be triggered, especially when stakeholders face unanticipated events (Maitlis, 2005). That the top three found perceived reaction patterns in this study were to (1) seek out more information, (2) engage in more informal communication, and (3) experience a feeling of insecurity supports the assumptions of, among others (Weick, 1995; Weick et al., 2005) and Maitlis and Christianson (2014), which argued that when stakeholders encounter ambiguous

or uncertain situations, they will seek to "make sense" of them through the use of existing organizational knowledge, networks and experiences. However, the search for explanatory cues is not always the final solution to the sensemaking process but rather pieces of information, which the sensemaker uses to form a schema that is often already shaped and influenced by existing states. Therefore, as argued by Cristofaro (2020), it is necessary to focus more on the role of affective states in determining possible cognition errors. That said, making sense of a crisis is not always easy as such an incident presents stakeholders with higher uncertainty levels (Mitroff et al., 1987) and limited information flow, often based upon less validated materials (Lu and Xue, 2016). Therefore, traditional information networks may not always prove sufficient, resulting in that co-workers seeking out information elsewhere.

While informal communication networks may have several benefits, there is an imminent danger that employees may fall victim to an illicit or little nuanced information flow. Combined with a higher degree of uncertainty, such information may negatively affect employees' sensemaking processes about their current and future (Keesee et al., 2008; Park, 2010). Signs of such negative ongoing processes are also identifiable in this study, as co-workers are, by their peers, perceived to show somewhat signs of misunderstanding, frustration, and insecurity, and some are also, to a degree, perceived to feel sorrow and fear. On a positive note, few perceived that their co-workers encountered a loss of motivation or wanted to leave the organization in a crisis. This may suggest that the Norwegian Sea Rescue Society (RS) is a resilient organization with the ability to counteract and adjust to triggering events. Emotional response findings also support the notion of organizational robustness. Few perceived that their co-workers reacted with a feeling of shame or betrayal when their organization experienced a crisis. On the contrary, the results indicate that RS employees consider their co-workers to handle crises well, as few perceived that typical crisis reaction patterns involved high degrees of passivity, silence, panic or loss of confidence.

Third, despite being a general notion, sensemaking can be viewed as a social construct, as organizations and individuals make sense based on their existing thoughts and feelings, thus already being affected by the "actual, imagined, or implied presence of others" (Allport and James, 1985, p. 3, cited in Weick, 1995, p. 39 and in Maitlis and Christianson, 2014, p. 66). As seen here, employees can positively or negatively impact the outcome of a crisis (Frandsen and Johansen, 2011) through their actions and behavior. Therefore, as Heide and Simonsson (2015) discussed, it is an essential management task to ensure that employees develop relevant crisis understanding, perspective, and awareness. An interesting observation in this study was that close to half of the sample, or more specifically, 35 individuals, while not belonging to the top management, perceived that they had crisis management and communication as part of their formal function. On the one hand, such high numbers may indicate an organization with unclear internally communicated roles and responsibilities. Conversely, the finding may reflect a relatively flat and transparent organizational structure, where top management trusts their employees and the employees take active ownership and contribute to their organization's overall crisis management.

Finally, a fourth critical element is that when people take action to make sense of a situation, it, in turn, affects the very environment they want to understand, thus creating "rational accounts of the world that enable action" (Maitlis, 2005, p. 21, cited in Maitlis and Christianson, 2014, p. 66). That well over half of the sample population had been with the organization for 6 years indicates That the Norwegian Sea Rescue Society (RS) has a stable employee pool. While a stable pool can be a strength both in everyday operations and in crisis, it can also result in extensive hierarchies, ingrained cultures and traditions that get in the way of effective crisis response (Downs, 1967; Berlin and Carlström, 2013). As employees often are the ones that are in the immediate position to notice early warning crisis signs and detect discrepancies, it is an essential management task to ensure that the employees develop and keeps up to date on their crisis sensemaking and awareness skills. As argued by Weick and Ashford (2001), employees who are empowered are, in crises, not only able to act through established and rehearsed procedures; they are also capable of improvising and implementing alternative solutions.

CONCLUSION, RECOMMENDATIONS AND LIMITATIONS

Findings showed that a majority perceived a crisis as an incident involving damage to stakeholders and that it was an incident that put parts of the organization out of operation within a short period. Fewer perceived that a crisis threatens the entire organization's existing foundation or is poorly handled by the organization's management. The results indicated that most of the sampled population strongly believed in their organization's overall resilience level, thus its ability to react and recover from damaging events or blows. However, the results also indicated a somewhat vague understanding of internal roles and responsibilities. Their need for more information became evident in co-workers' reaction patterns. The sample perceived that their co-workers engaged in informal communication and rumor spreading. Signs of ongoing negative processes were also identifiable in this study, as co-workers were by their peers perceived to show somewhat signs of misunderstanding, frustration, and insecurity. Crisis perception, knowledge of own organization, limitations and capabilities, roles, and responsibilities are important factors in crisis management that should be enhanced through communication and information sharing to prevent spreading rumors and functional disruption in an organization during a crisis. This paper deals with Norwegian employees. However, these findings' implications are global and include necessary

educational initiatives and research focusing on employees' perceptions of- and reactions to an organizational crisis. More research, preferably with the same approach, is recommended to gain further knowledge on how employees perceive and react to organizational crises. We recommend that future studies examine the relationships between variables using renowned statistical methods.

This study has several limitations. First, this study was limited in scope as data was collected from a limited sample population and a relatively short period. However, the response rate with associated achieved statistical power of 0.75 is close to the desired target of 0.80, hence giving a good indication of the current perceived understanding of crises and their responses. Second, the sample was presented only with predefined options, thus not providing individual options to define the different terms. Third, the sample had to interpret terms like crises, panic, and insecurity individually, which may cause lower term validity. Fourth, since the study was done during an ongoing pandemic, there is a bias in terms of the amount of information that existed at the time data was collected. Fifth, as this study focuses on individual perceptions only, there will always be a risk of bias or other barriers to perceptual accuracy. Finally, it should be noted that the original study was conducted on the organizational level among the 367 largest private companies and 98 public municipalities in Denmark (Johansen et al., 2012), while in this study, the same survey was used on a single organization and applied on the individual level. We still deem using the same instrument relevant, as it measures the participant's individual perceptions in both studies.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. The data is in Norwegian language only.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by NSD - Norwegian Centre for Research Data. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

JS: conceptualization, methodology, formal analysis, visualization, and project administration. JS, JR, LG, AK-M, KG, and AH: writing—original draft preparation and writing—review and editing. All authors contributed to the article and approved the submitted version.

ACKNOWLEDGMENTS

Reported data were collected as part of Master-thesis work of Fagerland (2020). The reported data in this article was not used as part of the thesis work and has never been reported on or published. The authors extend their appreciation to the Norwegian Sea Rescue Society for positively supporting and facilitating this study.

REFERENCES

Adamu, A. A., and Mohamad, B. (2019). Developing a strategic model of internal crisis communication: empirical evidence from Nigeria. *Int. J. Strateg. Commun.* 13, 233–254. doi: 10.1080/1553118X.2019.1629935

Aljuhmani, H. Y., and Emeagwali, O. L. (2017). The roles of strategic planning in organizational crisis management: The case of Jordanian banking sector. *Int. Rev. Manag. Mark.* 7, 50–60.

Allport, G., and James, W. (1985). *Psychology: The Briefer Course*. University of Notre Dame Press.

Altman, D. G. (1990). *Practical Statistics for Medical Research*. Florida: CRC press.

Ansell, C., Boin, A., and Keller, A. (2010). Managing transboundary crises: identifying the building blocks of an effective response system. *J. Conting. Crisis Manag.* 18, 195–207. doi: 10.1111/j.1468-5973.2010.00620.x

Bailey, K., and Breslin, D. (2021). The COVID-19 pandemic: what can we learn from past research in organizations and management? *Int. J. Manag. Rev.* 23, 3–6. doi: 10.1111/ijmr.12237

Barde, M. P., and Barde, P. J. (2012). What to use to express the variability of data: standard deviation or standard error of mean? *Perspect. Clin. Res.* 3, 113–116. doi: 10.4103/2229-3485.100662

Barton, A. H. (1970). *Communities in Disaster: A Sociological Analysis of Collective Stress Situations*. Ward Lock Educational.

Berlin, J. M., and Carlström, E. D. (2013). The dominance of mechanistic behaviour: a critical study of emergency exercises. *Int. J. Emerg. Manag.* 9, 327–350. doi: 10.1504/IJEM.2013.059878

Boin, A., and t Hart, P. (2022). From Crisis to reform? Exploring three post-COVID pathways. *Pol. Soc.* 41, 13–24. doi: 10.1093/polsoc/puab007

Bundy, J., Pfarrer, M. D., Short, C. E., and Coombs, W. T. (2017). Crises and crisis management: integration, interpretation, and research development. *J. Manag.* 43, 1661–1692. doi: 10.1177/0149206316680030

Burns, T., and Stalker, G.M. (1961). *The Management of Innovation*. London: Tavistock.

Christianson, M. K., Farkas, M. T., Sutcliffe, K. M., and Weick, K. E. (2009). Learning through rare events: significant interruptions at the Baltimore & Ohio Railroad Museum. *Organ. Sci.* 20, 846–860. doi: 10.1287/orsc.1080.0389

Cohen, J. (2013). *Statistical Power Analysis for the Behavioral Sciences*. London: Academic press.

Coombs, W. T., and Holladay, S. J. (2014). How publics react to crisis communication efforts: comparing crisis response reactions across sub-arenas. *J. Commun. Manag.* 18, 40–57. doi: 10.1108/JCOM-03-2013-0015

Cristofaro, M. (2020). "I feel and think, therefore I am": An affect-cognitive theory of management decisions. *Eur. Manag. J.* 38, 344–355. doi: 10.1016/j.emj.2019.09.003

Dewey, J. (1922). *Human Nature and Conduct*. Mineola, NY: Dover.

Downs, A. (1967). *Inside Bureaucracy*. New York: Little Brown.

Fagerland, O. M. B. (2020). Internal Crisis Communication: Case of The Norwegian Sea Rescue Society (Master's thesis, University of South-Eastern Norway).

Faul, F., Erdfelder, E., Buchner, A., and Lang, A.-G. (2009). Statistical power analyses using G* power 3.1: tests for correlation and regression analyses. *Behav. Res. Methods* 41, 1149–1160. doi: 10.3758/BRM.41.4.1149

Frandsen, F., and Johansen, W. (2011). *The Study of Internal Crisis Communication: Towards an Integrative Framework*. Corporate Communications: An International Journal.

Gephart, R. P. (1993). The textual approach: risk and blame in disaster sensemaking. *Acad. Manag. J.* 36, 1465–1514. doi: 10.5465/256819

Gilpin, D. R., and Murphy, P. J. (2008). *Crisis Management in a Complex World*. London: Oxford University Press.

Heide, M., and Simonsson, C. (2015). Struggling with internal crisis communication: a balancing act between paradoxical tensions. *Pub. Relat. Inq.* 4, 223–255. doi: 10.1177/2046147X15570108

Hernes, T., and Maitlis, S. (2012). *Process, Sensemaking, and Organizing*. London: Oxford University Press.

Hwang, P., and Lichtenthal, J. D. (2000). Anatomy of organizational crises. *J. Conting. Crisis Manag.* 8, 129–140. doi: 10.1111/1468-5973.00132

James, W. (1890). *The Principles of Psychology*. New York: Dover.

Johansen, W., Aggerholm, H. K., and Frandsen, F. (2012). Entering new territory: a study of internal crisis management and crisis communication in organizations. *Public Relat. Rev.* 38, 270–279. doi: 10.1016/j.pubrev.2011.11.008

Johansen, W., and Frandsen, F. (2007). *Crisis Communication: When the Corporate Image and Reputation Is Threatened [English Trans.]*. Frederiksberg, Denmark: Samfundslitteratur.

Keesee, N. J., Currier, J. M., and Neimeyer, R. A. (2008). Predictors of grief following the death of one's child: The contribution of finding meaning. *J. Clin. Psychol.* 64, 1145–1163. doi: 10.1002/jclp.20502

Kerchner, C. T., and Schuster, J. H. (1982). The uses of crisis: taking the tide at the flood. *Rev. High. Educ.* 5, 121–141. doi: 10.1353/rhe.1982.0011

Khorram-Manesh, A., Carlström, E., Hertelendy, A., Goniewicz, K., Casady, C., and Burkle, F. (2020). Does the prosperity of a country play a role in COVID-19 outcomes? *Disaster Med. Public Health Prep.* 16, 177–186. doi: 10.1017/dmp.2020.304

Kim, Y. (2018). Enhancing employee communication behaviors for sensemaking and sensegiving in crisis situations: strategic management approach for effective internal crisis communication. *J. Commun. Manag.* 22, 451–475. doi: 10.1108/JCOM-03-2018-0025

Klein, J. (2021). "Infectious disease, pandemics, and education: From miasms to COVID-19," in *Meeting the Challenges of Existential Threats Through Educational Innovation*. ed. H. Saeverot (Routledge), 85–97.

Kovoor-Misra, S., Clair, J. A., and Bettenhausen, K. L. (2001). Clarifying the attributes of organizational crises. *Technol. Forecast. Soc. Chang.* 67, 77–91. doi: 10.1016/S0040-1625(99)00081-5

Lalonde, C., and Roux-Dufort, C. (2013). Challenges in teaching crisis management: connecting theories, skills, and reflexivity. *J. Manag. Educ.* 37, 21–50. doi: 10.1177/1052562912456144

Laroche, H. (1995). From decision to action in organizations: decision-making as a social representation. *Organ. Sci.* 6, 62–75. doi: 10.1287/orsc.6.1.62

Linnenluecke, M. K. (2017). Resilience in business and management research: A review of influential publications and a research agenda. *Int. J. Manag. Rev.* 19, 4–30. doi: 10.1111/ijmr.12076

Longstaff, P. H. (2005). *Security, Resilience, and Communication in Unpredictable Environments Such as Terrorism, Natural Disasters, and Complex Technology*. England: Center for Information Policy Research, Harvard University.

Louis, M. R. (1980). Surprise and sensemaking: what newcomers experience in entering unfamiliar settings. *Adm. Sci. Q.* 25, 226–251. doi: 10.2307/2392453

Lu, X., and Xue, L. (2016). Managing the unexpected: sense-making in the Chinese emergency management system. *Public Adm.* 94, 414–429. doi: 10.1111/padm.12261

Magnussen, L. I., Carlstrøm, E., Berge, A.-K., Wegger, F., and Sørensen, J. L. (2018). Help we are sinking! Stories from Norwegian dispatch centers on decision-making in unfamiliar and ambiguous situations. *J. Emerg. manag.* 16, 245–254. doi: 10.5055/jem.2018.0373

Maitlis, S. (2005). The social processes of organizational sensemaking. *Acad. Manag. J.* 48, 21–49. doi: 10.5465/amj.2005.15993111

Maitlis, S., and Christianson, M. (2014). Sensemaking in organizations: taking stock and moving forward. *Acad. Manag. Ann.* 8, 57–125. doi: 10.5465/19416520.2014.873177

Maitlis, S., Vogus, T. J., and Lawrence, T. B. (2013). Sensemaking and emotion in organizations. *Organ. Psychol. Rev.* 3, 222–247. doi: 10.1177/2041386613489062

Milburn, T. W., Schuler, R. S., and Watman, K. H. (1983). Organizational crisis. Part I: definition and conceptualization. *Hum. Relat.* 36, 1141–1160. doi: 10.1177/001872678303601205

Mitroff, I. I., Shrivastava, P., and Udwadia, F. E. (1987). Effective crisis management. *Acad. Manag. Perspect.* 1, 283–292. doi: 10.5465/ame.1987.4275639

Namvar, M., Cybulski, J., Phang, C., Wee, C.-Y., and Tan, K. Y. (2018). Simplifying sensemaking: concept, process, strengths, shortcomings, and ways forward for information systems in contemporary business environments. *Australas. J. Inf. Syst.* 22:1645. doi: 10.3127/ajis.v22i0.1654

Norwegian Government (2020). Omfattende tiltak for å bekjempe koronaviruset. Available at: https://www.regjeringen.no/no/aktuelt/nye-tiltak/id2693327/ (Accessed November 11, 2020).

Norwegian Institute of Public Health (2020). Status koronavirus 12. mars 2020. Available at: https://www.fhi.no/nyheter/2020/status-koronavirus-12.-mars-2020/ (Accessed November 11, 2020).

Nystrom, P., and Starbuck, W. H. (2015). To Avoid Organizational Crises, Unlearn. Available at: https://ssrn.com/abstract=2708289

Park, C. L. (2010). Making sense of the meaning literature: an integrative review of meaning making and its effects on adjustment to stressful life events. *Psychol. Bull.* 136, 257–301. doi: 10.1037/a0018301

Pearson, C. M., and Clair, J. A. (1998). Reframing crisis management. *Acad. Manag. Rev.* 23, 59–76. doi: 10.2307/259099

Pearson, C. M., and Mitroff, I. I. (1993). From crisis prone to crisis prepared: a framework for crisis management. *Acad. Manag. Perspect.* 7, 48–59. doi: 10.5465/ame.1993.9409142058

Peyravi, M., Marzaleh, M. A., and Khorram-Manesh, A. (2021). "A disaster: Genral principles and management," in *Handbook of Disaster and Emergency Management. 2nd Edn*. eds. A. Khorram-Manesh, K. Goniewicz, A. Hertelendy and M. Dulebenets (Göteborg: Kompendiet).

Prior, D. D., Keränen, J., and Koskela, S. (2018). Sensemaking, sensegiving and absorptive capacity in complex procurements. *J. Bus. Res.* 88, 79–90. doi: 10.1016/j.jbusres.2018.03.009

Redningsselskapet (2020). Welcome to the Norwegian sea rescue society. Available at: https://www.redningsselskapet.no/english/ (Accessed November 11, 2020).

Roux-Dufort, C., and Lalonde, C. (2013). Exploring the Theoretical Foundations of Crisis Management. *J. Conting. Crisis Manag.* 21, 1–3.

Seidl, D., and Werle, F. (2018). Inter-organizational sensemaking in the face of strategic meta-problems: requisite variety and dynamics of participation. *Strateg. Manag. J.* 39, 830–858. doi: 10.1002/smj.2723

Smart, C., and Vertinsky, I. (1984). Strategy and the environment: A study of corporate responses to crises. *Strateg. Manag. J.* 5, 199–213. doi: 10.1002/smj.4250050302

Sonenshein, S. (2010). We're changing—Or are we? Untangling the role of progressive, regressive, and stability narratives during strategic change implementation. *Acad. Manag. J.* 53, 477–512. doi: 10.5465/amj.2010.51467638

Sørensen, J. L. (2017). Norwegian maritime crisis collaboration exercises: are they useful? Doctoral dissertation, Northcentral University.

Sriharan, A., Hertelendy, A. J., Banaszak-Holl, J., Fleig-Palmer, M. M., Mitchell, C., Nigam, A., et al. (2022). Public health and health sector crisis leadership during pandemics: a review of the medical and business literature. *Med. Care Res. Rev.* 79, 475–486. doi: 10.1177/10775587211039201

Starbuck, W. H., and Milliken, F. J. (1988). "Executives' perceptual filters: what they notice and how they make sense," in *The Executive Effect: Concepts and Methods for Studying Top Managers*. ed. D. C. Hambrick (Greenwich, CT: JAI Press), 35–65.

Steen, R., and Morsut, C. (2020). Resilience in crisis management at the municipal level: The synne storm in Norway. *Risk, Hazards Crisis Pub. Pol.* 11, 35–60. doi: 10.1002/rhc3.12178

Tan, B., Pan, S. L., Chen, W., and Huang, L. (2020). Organizational Sensemaking in ERP implementation: The influence of Sensemaking structure. *MIS Q.* 44, 1773–1809. doi: 10.25300/MISQ/2020/11872

Teo, W. L., Lee, M., and Lim, W. S. (2017). The relational activation of resilience model: how leadership activates resilience in an organizational crisis. *J. Conting. Crisis Manag.* 25, 136–147. doi: 10.1111/1468-5973.12179

Van Wart, M., and Kapucu, N. (2011). Crisis management competencies: The case of emergency managers in the USA. *Public Manag. Rev.* 13, 489–511. doi: 10.1080/14719037.2010.525034

Weick, K. E. (1969). *The Social Psychology of Organizing*. Reading, MA: Addison-Wesley.

Weick, K. E. (1988). Enacted sensemaking in crisis situations [1]. *J. Manag. Stud.* 25, 305–317. doi: 10.1111/j.1467-6486.1988.tb00039.x

Weick, K. E. (1990). The vulnerable system: an analysis of the Tenerife air disaster. *J. Manag.* 16, 571–593. doi: 10.1177/014920639001600304

Weick, K. E. (1993). The collapse of sensemaking in organizations: The Mann gulch disaster. *Adm. Sci. Q.* 38, 628–652. doi: 10.2307/2393339

Weick, K. E. (1995). *Sensemaking in Organizations*. United States: Sage.

Weick, K. E. (2010). Reflections on enacted sensemaking in the Bhopal disaster. *J. Manag. Stud.* 47, 537–550. doi: 10.1111/j.1467-6486.2010.00900.x

Weick, K. E. (2012). *Making Sense of the Organization, Volume 2: The Impermanent Organization*. New Jersey: John Wiley & Sons.

Weick, K. E. (2015). The social psychology of organizing. *Management* 18:189.

Weick, K. E., and Ashford, S. J. (2001). Learning in organizations. *New Handbook of Organ. Commun. Adv. Theor. Res. Methods* 704:731.

Weick, K. E., Sutcliffe, K., and Obstfeld, D. (2005). Organizing and the process of sensemaking. *Organ. Sci.* 16, 409–421. doi: 10.1287/orsc.1050.0133

Williams, T. A., Gruber, D. A., Sutcliffe, K. M., Shepherd, D. A., and Zhao, E. Y. (2017). Organizational response to adversity: fusing crisis management and resilience research streams. *Acad. Manag. Ann.* 11, 733–769. doi: 10.5465/annals.2015.0134

Winston, B. E. (ed.) (2019). "Leadership growth through crisis: an investigation of leader development during tumultuous circumstances," in *Communicating Through Crisis*. Switzerland: Palgrave.

Wolbers, J., Kuipers, S., and Boin, A. (2021). A systematic review of 20 years of crisis and disaster research: trends and progress. *Risk, Hazards Crisis Pub. Pol.* 12, 374–392. doi: 10.1002/rhc3.12244

Zamoum, K., and Gorpe, T. S. (2018). "Crisis management: a historical and conceptual approach for a better understanding of today's crises," in *Crisis Management-Theory and Practice*. eds. K. Holla, M. Titko and J. Ristvej (United Kingdom: IntechOpen).

Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's Note: All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

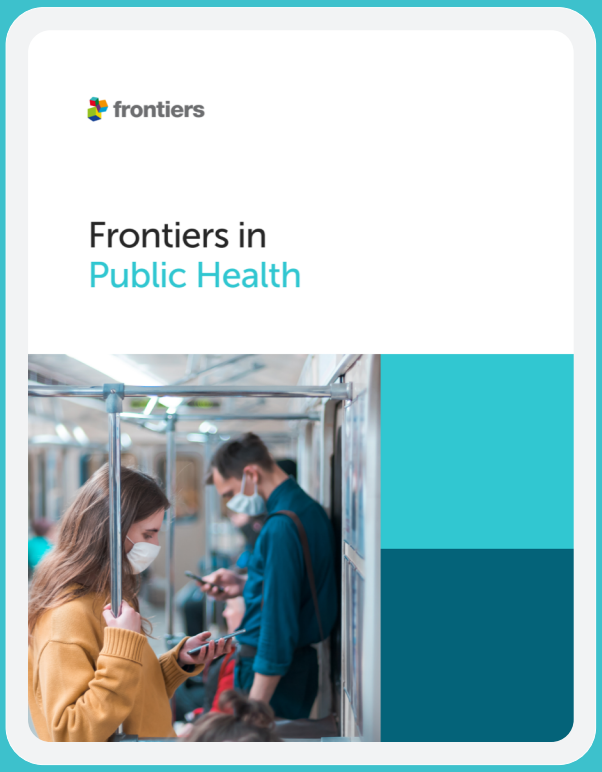
Frontiers in Public Health

Explores and addresses today's fast-moving healthcare challenges

One of the most cited journals in its field, which promotes discussion around inter-sectoral public health challenges spanning health promotion to climate change, transportation, environmental change and even species diversity.

Discover the latest Research Topics

See more →



Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact