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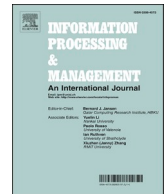
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## The causes, impacts and countermeasures of COVID-19 “Infodemic”: A systematic review using narrative synthesis

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### ABSTRACT

An unprecedented infodemic has been witnessed to create massive damage to human society. However, it was not thoroughly investigated. This systematic review aims to (1) synthesize the existing literature on the causes and impacts of COVID-19 infodemic; (2) summarize the proposed strategies to fight with COVID-19 infodemic; and (3) identify the directions for future research. A systematic literature search following the PRISMA guideline covering 12 scholarly databases was conducted to retrieve various types of peer-reviewed articles that reported causes, impacts, or countermeasures of the infodemic. Empirical studies were assessed for risk of bias using the Mixed-Methods Appraisal Tool. A coding theme was iteratively developed to categorize the causes, impacts, and countermeasures found from the included studies. Social media usage, low level of health/eHealth literacy, and fast publication process and preprint service are identified as the major causes of the infodemic. Besides, the vicious circle of human rumor-spreading behavior and the psychological issues from the public (e.g., anxiety, distress, fear) emerges as the characteristic of the infodemic. Comprehensive lists of countermeasures are summarized from different perspectives, among which risk communication and consumer health information need/seeking are of particular importance. Theoretical and practical implications are discussed and future research directions are suggested.

### 1. Introduction

The COVID-19 pandemic had caused over 2.99 million deaths from over 139 million reported cases as of April 17, 2021 (the date when this manuscript was submitted), as well as the worst global economic recession since World War II (Corona Virus World meters; The World Bank 2020). Simultaneously, an unprecedented “Infodemic” has been witnessed, described as a worldwide epidemic of the rapid spreading of rumors and conspiracy theories through various platforms (Zarocostas, 2020; The Lancet Infectious Diseases 2020). The WHO’s director-general, Tedros Adhanom Ghebreyesus, said that “We’re not just fighting with a pandemic; we’re fighting an infodemic”, as it brought the situation even worse.

“We’re not just fighting an epidemic; we’re fighting an infodemic”—Tedros Adhanom Ghebreyesus, WHO Director-General.

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The term infodemic was coined in 2003 by David Rothkopf, a writer for Washington Post (Rothkopf, 11 May 2003). It has different definitions, varying from "a few facts, mixed with fear, speculation, and rumor, amplified and relayed swiftly worldwide by modern information technologies" to "a rapid and far-reaching spread of both accurate and inaccurate information about something, such as a disease" by Merriam-Webster dictionary.

It has been used sporadically since then but is re-emphasized recently by WHO as the worldwide challenge for global health. Since not enough attention was paid to this topic until recently, it may not be thoroughly investigated or understood. A recent systematic review on COVID-19 misinformation was found in the pilot search (Ali, 2020). However, it merely focused on its impacts and did not perform a systematic literature search, with only 35 articles included from a pre-selected list of journals.

Hence, it is important to collect and review the articles on this topic in a more rigorous way to further our understanding, summarize the current research, and provide suggestions for future research. The objectives of this review are: 1) synthesize the existing literature on the causes and impacts of COVID-19 infodemic; 2) summarize the proposed countermeasures to fight with COVID-19 infodemic; 3) identify the directions for future research.

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)\* guideline was used in this review as the research protocol. It is recommended by leading medical journals (e.g., LANCET, JAMA, and BMJ) and widely used to conduct systematic reviews and meta-analyses in various domains related to health to assure research rigor. It provides recommendations on what to report and how to report in each section of a systematic review or meta-analysis. For example, it requires authors to report the rationale and objectives to conduct a particular review, the search strategy, eligibility criteria, and information sources. As the studies included in this review adopted different research methods (e.g., quantitative and qualitative) and are heterogeneous in nature, a narrative synthesis approach was used to synthesize the findings. Hence, the part of the guideline on meta-synthesis was not used in this review.

It is found from the review that social media usage and low level of health/eHealth literacy were major causes of the infodemic, and the fast publication process and preprint service were possible causes. Besides, the vicious circle of human rumor-spreading behavior that fed psychological stresses of public social media users (e.g., anxiety, distress, fear) emerged as a dominant characteristic of the infodemic, which was not investigated in previous studies. A comprehensive list of countermeasures is collated from different

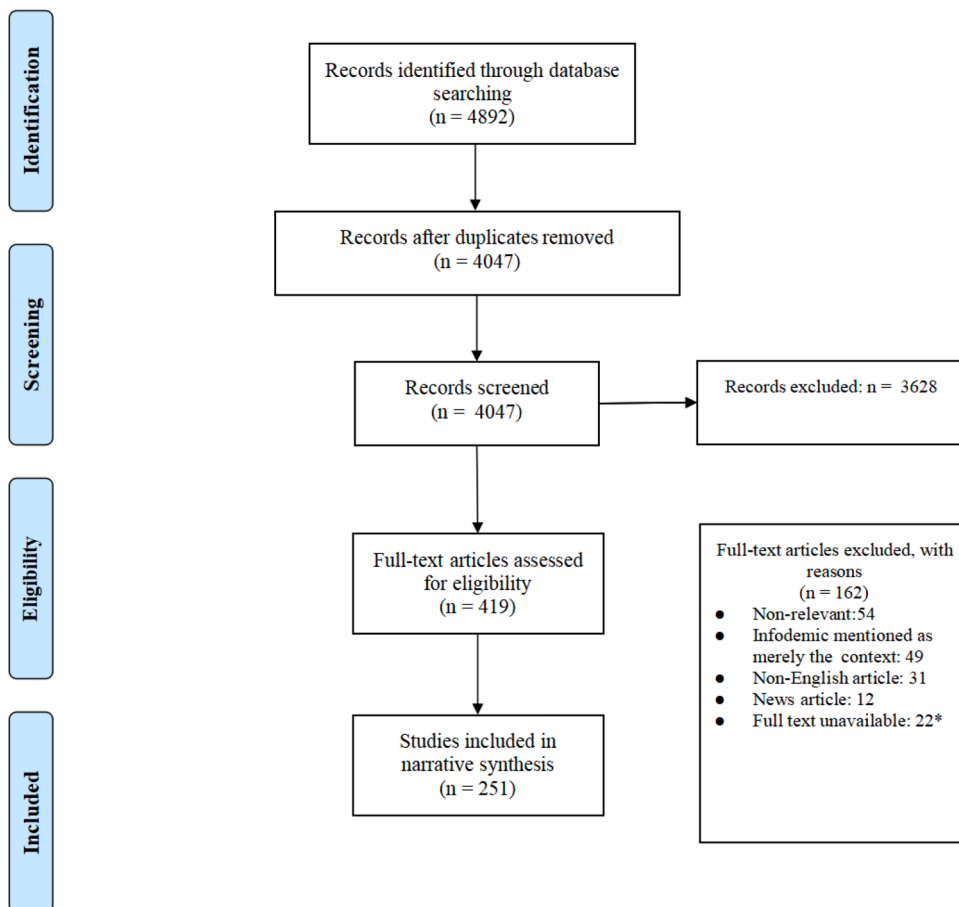


Fig. 1. Article screening and selection. All of the articles with full text unavailable were non-empirical (e.g., commentary, letter, viewpoint).

perspectives, including risk communication and consumer health information need/seeking, which are of particular importance. Future research should investigate bidirectional relationships between rumor-spreading/sharing behavior and human psychological issues, social media “publication” (e.g., like, retweet, share), their impact on the infodemic, and the effectiveness of the various countermeasures.

**Table 1**  
Coding framework.

| Coding categories                | Sub categories  | Instances  |
|----------------------------------|---|--|
| <b>Causes</b>                    | Lack of health literacy/eHealth literacy                    | "A recent poll from the Pew Research Center showed that half of Americans find it difficult to determine what is true and not true about the outbreak (pewrsr.ch/2YJRJ98)" [104, pp. 38]<br>"Poor information access, as well as infodemic and poor health literacy in rural areas of Africa, have been a challenge." [100, pp. 2]   |
|                                  | Fast publication process & preprint service                 | "Posting research to preprint servers is also to blame. Science has embraced them as a way of quickly disseminating preliminary findings." [117, pp. 7]<br>"In this sample, 260 articles were published within 7 days of submission. Researchers have cautioned about interpretation of research findings during a crisis." [141, pp. 2]   |
|                                  | Social media usage  | "Of the 1225 fake news stories analysed, social media accounted for spreading half (619, 50.5%) of the stories about COVID-19" [16, pp. 2]<br>"A total of 200 of the most viewed YouTube videos from January 1, 2020, to April 30, 2020, were screened, of the 105 total videos, 37.14% (39/105) contained misleading information." [56, pp. 1]  |
|                                  | Others  | "Incorrect use of bubble charts and heat maps and overly crowded dot/pin maps indicating COVID-19 cases or medical facility locations." [50, pp. 266]  |
| <b>Impacts</b>                   | Public psychological issues                                 | "different groups of people have different psychological issues-postive patients & quarantined individuals: loneliness, anxiety, PTSD, depression; health care providers: fear of worthlessness, guilt, overwhelming work-pressure." [166, pp. 782]<br>"These extreme circumstances and uncertainty can result in exacerbation of anxiety, sleep disturbances, depression, obsessions, compulsions, and even psychotic symptoms such as paranoia." [167, pp. 1]  |
|                                  | Trust loss  | "This situation is extremely concerning because it undermines trust in health institutions and programs." [4, pp. 875]<br>"In this context, Italy suffers from a general lack of trust in public institutions." [197, pp. 459]   |
|                                  | Inappropriate protective measures                           | "Misinformation caused more than 27 deaths by direct consumption of alcohol and detergents to avoid the risk of coronavirus in Iran" [187, pp. 2]<br>"This way of attempting to deal with this virus situation will bring discriminatory attitudes and trauma together toward older adults." [189, pp. 632]  |
|                                  | Panic purchase  | "rumours and misinformation led to a surge of sales in herbal remedies in China and antimalarial drugs worldwide, and timely clarification of rumours mitigated the rush to purchase unproven remedies." [202, pp. 1]  |
| <b>Countermeasure strategies</b> | For lack of health literacy/eHealth literacy/media literacy | "There is a proposal to include health preventive measures into elementary and high school curricula." [115, pp. 585]<br>"Focus on people: Health literacy is (also) media literacy." [217, pp. 2]   |
|                                  | For governments & organizations                             | "The Ministry urged people to share only official information, accompanied by the hashtag 'Don't Spread #FakeNews.' It further indicated that those who create and/or share false information to benefit themselves or cause perjury to others will receive a 2- to 4-year prison sentence." [115, pp. 584]<br>"In April, the Italian government launched a specific task force to promote collaboration with fact-checkers and to encourage citizens' activism in signaling misinformation." [197, pp. 460] |
|                                  | For social media/mass media platforms                       | "Newspapers and television channels will also have to undertake fact-checking functions, particularly to debunk fake news, misinformation and disinformation on health subjects." [208, pp. 1446]<br>"Tech giants have responded with information regarding their own plans to fight COVID-19 misinformation and disinformation on their platforms." [223, pp. 1]  |
|                                  | For risk communication                                      | "Also, risk communication should be embedded in all aspects of the response, whether it is about people doing contact tracing, or caring for the sick. While some expertise is certainly needed to develop a plan, and develop strategies and messages, risk communication shouldn't be only for the experts." [18, pp. 3]   |
|                                  | For public health information needs/seeking                 | "Governments should reach out to key communities to ensure their concerns and information needs are understood, tailoring advice and messages to address the audiences they represent." [227, pp. 2]   |

## 2. Methods

### 2.1. Search strategy and selection criteria

The PRISMA guideline was followed in this review, with twelve databases searched: PubMed, CINAHL Complete, Psych INFO, Psych Articles, ScienceDirect, Wiley Online Library, Web of Science, EBSCO, Communication & Mass Media Complete, Library, Information Science & Technology Abstracts, and Psychology and Behavioral Sciences Collection. The query "(infodemic OR infodemiology) OR ((COVID-19 OR SAR-COV-2 OR coronavirus) AND (misinformation OR rumor OR rumour OR disinformation OR conspiracy theory OR fake news))" was used to retrieve records within the title, keywords, and abstract fields with no date restrictions since we wanted to find out as many articles on this topic as possible. References of the included articles were backward-tracked, and Google Scholar was searched to identify extra potentially relevant articles. The literature search was conducted on January 9, 2021.

Four thousand eight hundred and ninety-two records were retrieved from the literature search, with 4047 retained after removing duplicates. The first round of screening of article abstracts was conducted by The first and second authors. To assess selection reliability between different coders, many reviews picked a small random sample of abstracts for coding by two or more coders to calculate inter-rater reliability. For this review, all of the retrieved abstracts were screened by two authors. Once discrepancies were encountered, the third author was involved in deciding whether this abstract would be retained for the full-text screening. Two hundred and fifty-one articles were finally selected for this review. The full-text screening was performed by the first and second authors for final inclusion, following the same procedure. Discrepancies were resolved through discussion between these two authors or consultation with the third author. A consensus was reached for each included study. The detailed screening and selection process is shown in Fig. 1. The detailed screening and selection process was shown in Fig. 1. An article was included in this review if the following inclusion criteria were met: 1) published in a peer-reviewed journal; 2) written in English; 3) the focus of this article was on the consequence, cause, or countermeasure strategies of infodemic rather than it was mentioned merely as the context; 4) Not news articles.

### 2.2. Data analysis

Different types of articles were included in this review: qualitative study, quantitative study, commentary, letter, and opinion paper published in peer-reviewed journals. The following information from the included articles was extracted: title, journal name, publication date, country (from the affiliation of the first author), article type, as well as the causes, impacts, and countermeasure strategies of the infodemic. A narrative synthesis approach was applied to synthesizing the findings from different articles since they were methodologically heterogeneous (Popay et al., 2006). A coding scheme was developed by an iterated coding process to categorize these findings. For instance, if one particular cause was identified from a particular article during the coding, WJ tried to assign it to a specific category within the cause framework. A new subcategory was created if the current categories are not suitable until all the causes were categorized. The same procedure was performed for the impacts and countermeasures. Another author JX did a second round of coding to validate the scheme. The discrepancies were resolved by discussion, and a third author FC was introduced when the consensus was not reached. The details of the coding scheme were provided in Table 1.

The empirical studies included in this review were evaluated for the risk of bias. A mixed-methods assessment tool (MMAT) was used to score each of them (Pluye et al., 2011). For each type of empirical study, a list of seven dichotomous criteria was used to evaluate the risk of bias (7 points in total), for which five points or above indicated a low level of risk and below three points indicated a high level. The ratings were available in the Appendix. For the non-empirical articles, their findings require further validation since their risks of bias were not able to be assessed. However, they were also peer-reviewed (with references), hence able to provide more perspectives on the understanding of the infodemic.

## 3. Results

### 3.1. Causes of the infodemic

Social media usage, low level of health/eHealth literacy were identified as the major causes of the infodemic, and the fast publication process and preprint service were identified as possible causes. Other causes included ideology, information overloads, financial incentives, and large-scale lockdown. Besides, the vicious circle of human rumor-spreading behavior and the psychological issues from the public (e.g., anxiety, distress, fear) emerged as the characteristic of the infodemic.

#### 3.1.1. Social media usage

One of the major causes of the infodemic is social media usage (Durodolu and Ibenne, 2020; Ali, 2020). Although thought of as both the antidote to and culprit of the infodemic (Radu, 2020), it played more of a negative role than a positive one. Various commentaries, letters, viewpoints, and editorials pointed out the negative roles it had played during the infodemic (Radu, 2020; Datta et al., 2020; Stephens, 2020; Orso et al., 2020; Naeem et al., 2020; Sahu and Agrawal, 2020; JCIH Editorial Team 2020; Nguyen and Nguyen, 2020; Rathore and Farooq, 2020; Bunker, 2020; Ahmed Siddiqui et al., 2020; Allahverdipour, 2020; Buchanan, 2020; Jalali and Mohammedi, 2020; Krittanawong et al., 2020; Kulkarni et al., 2020; Love et al., 2020; Marin, 2020; Mian and Khan, 2020; Moran, 2020; Ostrovsky and Chen, 2020; Rosenberg et al., 2020; Vasconcellos-Silva and Castiel, 2020; Viswanath et al., 2020; Wormer, 2020; Mokhtari and Mirzaei, 2020; Mheidly and Fares, 2020; Kearsley and Duffy, 2020; Mondiale de la Santé, 2020; Sasidharan et al., 2020; Gottlieb and Dyer, 2020; Zucker, 2020; Chou et al., 2021; Nelson et al., 2020; Burtscher et al., 2020; Greene et al., 2020; Yap and Xie,

2020; Vraga and Jacobsen, 2020; Mooney and Juhász, 2020), which were shown below with support from empirical studies.

First, it served as the platform where misinformation was circulated. The prevalence of misinformation on social media platforms was identified in different platforms and countries. For example, social media was found responsible for spreading 50.5% of the fake stories identified during the first months of the pandemic (Naeem et al., 2020). Over 37% of the most viewed YouTube videos with the Korean term "Coronavirus" and its variations were found to contain misleading information (Andreu-Sánchez and Martín-Pascual, 2020). High percentages of misinformation were also found when the search was conducted in English or on other platforms (e.g., Facebook and Twitter) (Li et al., 2020; Ahmed et al., 2020; Ahmed et al., 2020). Similar findings were also reported by a considerable amount of studies (Ahmed et al., 2020; Pulido et al., 2020; Moon and Lee, 2020; Bărgăoanu and Durach, 2020; Khatri et al., 2020; Ataç et al., 2020; D'Souza et al., 2020; Dutta et al., 2020; Kocyigit et al., 2020; Yüce et al., 2020; Yuksel and Cakmak, 2020; Kawchuk et al., 2020; Raja and Shaheed, 2020; Almomani and Al-Qur'an, 2020; Cuan-Baltazar et al., 2020; Szmuda et al., 2020; Moscadelli et al., 2020; Obiała et al., 2021; Mackey et al., 2020; Safarnejad et al., 2020; Tagliabue et al., 2020).

Second, the positive relationship between social media usage and rumor spreading was identified. Social media usage and dependency were found to directly predict the intention of rumor sharing in different populations (Apuke and Omar, 2020; Sun et al., 2020; Apuke and Omar, 2021). Furthermore, it contributed to the infodemic by increasing the public's misinformation beliefs (Sun et al., 2020) — people who believe it actually tweet it (Ahmed et al., 2020; Islam et al., 2020). For example, the more people relied on social media, the more they endorsed rumors among them (Dhanani and Franz, 2020). Exposure to social media was also found to significantly increase the susceptibility of rumor and deception (Safarnejad et al., 2020; Naidoo, 2020; Roozenbeek et al., 2020; Thomas et al., 2020). More studies were found to confirm the effect of social media usage on the formation of misinformation beliefs (Romer and Jamieson, 2020; Lee et al., 2020; Allington et al., 2020; Freeman et al., 2020; Bastani and Bahrami, 2020).

Third, it caused psychological issues among the public, which contributed to the rumor spreading in return, characterized as the vicious cycle of the infodemic (Kouzy et al., 2020). A survey study based on a representative sample of U.S. citizens found that the positive relationship between social media usage and misinformation beliefs was mediated by the public's worry—a particular type of psychological issue (Su, 2021). In addition, other psychological issues (e.g., anxiety, fear, and depression) were found due to rumor spreading and social media usage (Sahu and Agrawal, 2020; Williams Kirkpatrick, 2020; Lwin et al., 2020; Lin et al., 2020; Ni et al., 2020; Pahayahay and Khalili-Mahani, 2020; Ahmad and Murad, 2020). Hence, the infodemic was finally exacerbated by social media usage via these psychological issues, which were reviewed as the impacts of the infodemic in a later section.

### 3.1.2. Low level of health/eHealth literacy

Another major cause of the infodemic is the low level of health/eHealth literacy, which referred to the ability to obtain, process, and understand health information and finally make health decisions (Berkman et al., 2010; Kindig et al., 2004; Baur, 2020). Numerous editorials and commentaries were also found to point out its negative role during the infodemic (Mokhtari and Mirzaei, 2020; Tagliabue et al., 2020; Nguyen and Catalan, 2020; Ogunkola et al., 2020; Hanspal and Hanspal, 2020; Lucero-Prisno et al., 2020; Sentell et al., 2020; Kletter, 2020; Cangussú et al., 2020; Jindal and Anand, 2020; Paakkari and Okan, 2020; Vanderpool et al., 2020; Okereke et al., 2020; Greenspan and Loftus, 2021; Schiavo, 2020; Morgan-Daniel et al., 2020; Scherer and Pennycook, 2020; Eysenbach, 2020; Alvarez-Risco et al., 2020; Ghazal Aghagoli et al., 2020; Anon, 2020; Chong et al., 2020), which was supported by the evidence from a considerable number of empirical studies. For example, a low level of health/eHealth literacy was found positively related to the conspiracy beliefs in different countries (Duplaga, 2020; Pickles et al., 2020; Okan et al., 2020; Sallam et al., 2020; Sallam et al., 2020), which further contributed to the rumor spreading, as mentioned earlier. Moreover, subjective knowledge of science was found to reduce the willingness to share rumors, which indicated that a low level of health/eHealth literacy would increase the intention to share (Williams Kirkpatrick, 2020).

### 3.1.3. Fast publication process & preprint service

Various editorials, commentaries, viewpoints, and perspectives also mentioned the fast publication process and preprint service as the major causes of the infodemic (Mheidly and Fares, 2020; Kearsley and Duffy, 2020; Anon, 2020; Aguilar, 2020; Baker et al., 2020; Iskander and Bianchi, 2021; King, 2020; Koerber, 2021; Mayo-Yáñez, 2020; Solomon et al., 2020; Toth et al., 2020; Ruffell, 2020; Henrina et al., 2021; Larson, 2020; Naeem and Bhatti, 2020; Sahoo et al., 2020; Khan, 2020; Casigliani et al., 2020; Barbosa et al., 2020). At present, there was no empirical study found to investigate the effect of fast publication on rumor spreading directly. However, studies found that during the first months of the pandemic, over one thousand COVID-19 articles were published, with only less than 300 articles being original research (Gazendam et al., 2020; Kambakamba et al., 2020). In addition, the fast speed of peer-review/publication for medical papers undermined their scientific quality: for the journals where the COVID-19 articles were published, the median duration for a regular peer review was fifty-six days, while the median for COVID-19 related articles was only eight days (Khalifa and Ahmed, 2021).

Preprint service fuels the situation by providing non-reviewed manuscripts. A significant portion of these manuscripts cannot finally be published due to their low quality (Ruffell, 2020). However, they could be cited and used on social media platforms before they are qualified for publication. A notorious case was that a preprint paper indicating the positive effect of Vitamin-D on reducing the mortality of COVID-19 patients was used more than 100,000 times, which was cited even by an article from BMJ. Further investigation found that the authors' identities could not be verified, as well as the severe flaws among their data (Henrina et al., 2021). Moreover, the retraction of high-profile COVID-19 papers from the preprint service during the pandemic caused the public to question the authority and increase their potential to believe rumors (Solomon et al., 2020).

It should be noticed that no empirical study was conducted to confirm the causality between the infodemic and the fast publication process and preprint service. It is without question that the fast publication process (faster than before) and preprint service also play a

positive role in terms of disseminating accurate information timely. A possible reason why many comments and opinions mentioned them as the cause is that when related to the infodemic, their negative role is more apparent. Hence, it should be considered as only a proposed cause at this stage to be validated in the future.

### 3.1.4. Other causes

A few other causes were identified from this review: ideology (Chou et al., 2021; Okereke et al., 2020; Scherer and Pennycook, 2020; Ghazal Aghagholi et al., 2020; Cichocka, 2020; Hauer and Sood, 2020), health information needs and overloads (Greenspan and Loftus, 2021; Morgan-Daniel et al., 2020; Garcia and Duarte, 2020; Larson, 2020), civil literacy (Schiavo, 2020), the armchair scientist phenomenon (Chong et al., 2020), inappropriate usage of map information (Mooney and Juhász, 2020), the distrust of government (Mondiale de la Santé, 2020; Chou et al., 2021; Horton, 2020), financial incentives and lack of supervision (Bastani and Bahrami, 2020), and large scale lockdown (Kulkarni et al., 2020; Sasidharan et al., 2020; Cichocka, 2020). Only ideology was quantitatively investigated: people with certain ideological characteristics (e.g., general skepticism, cultural/political orientation, and conservatism) were found more susceptible to rumors (Calvillo et al., 2020; Alper et al., 2020; Georgiou et al., 2020; Biddlestone et al., 2020; Havey, 2020).

It was noticeable that the empirical studies in this section mainly took the survey as the research method, and randomization sampling was not used in these surveys, which made the samples less representative and the results potentially biased.

### 3.2. Impacts of the infodemic

The following negative impacts were identified from this review: the public psychological issues, breakdown of trust, inappropriate protective measures, panic purchase, and finally, the global economy.

Various psychological issues raised during the pandemic were attributed to the infodemic—loneliness, anxiety, depression, PTSD, fear, and other neurological complications (Ahmed Siddiqui et al., 2020; Jalali and Mohammadi, 2020; Kulkarni et al., 2020; Mheidly and Fares, 2020; Nelson et al., 2020; Tagliabue et al., 2020; Garcia and Duarte, 2020; Sezgin et al., 2020; Sacchelli et al., 2020; Sandu, 2020; Depoux et al., 2020; Scerri and Grech, 2020; Lima et al., 2020; Shimizu, 2020; Looi et al., 2020; Patel et al., 2020; Tasnim et al., 2020; Peters, 2020; Neal and Zheng, 2020; Dubey et al., 2020; Shanbour et al., 2020). Empirical studies found that misinformation and the spreading of rumors caused various types of psychological issues among the public (Bratu, 2020; Radwan et al., 2020; Dong et al., 2020; Gao et al., 2020; Sharov, 2020; Secosan et al., 2020; Siebenhaar et al., 2020; Marín et al., 2020). In addition, public conspiracy beliefs, which were the manifestation of the infodemic, were also found to raise various psychological issues not only among the public but also among the medical practitioners (Durodolu and Ibenne, 2020; Bastani and Bahrami, 2020; Sallam et al., 2020; Chen et al., 2020). These psychological issues reciprocally accelerate the spreading of rumors, contributing to the vicious circle of the infodemic, as mentioned earlier.

Another negative consequence of the infodemic was the inappropriate protective behavior performed by the public and even the avoidable death of them (Ahmed Siddiqui et al., 2020; Jalali and Mohammadi, 2020; Kulkarni et al., 2020; Love et al., 2020; Nelson et al., 2020; Tagliabue et al., 2020; Garcia and Duarte, 2020; Sandu, 2020; Scerri and Grech, 2020; Lima et al., 2020; Tasnim et al., 2020; Taylor, 2020; Galvão, 2020; Tapia, 2020; Cheema et al., 2020; Cuartas-Arias, 2020; Ingraham and Tignanelli, 2020; O'connor and Murphy, 2020; van der Linden et al., 2020; Tuccori et al., 2020; Hashmi et al., 2020; Gavgani, 2020; Anon, 1992; Rahman and Jahan, 2020). The low intention of wearing masks, keeping social distance, and taking vaccination was found due to a high level of conspiracy beliefs and susceptibility of rumors among the public in the U.S. and other countries (Ali, 2020; Roozenbeek et al., 2020; Romer and Jamieson, 2020; Allington et al., 2020; Biddlestone et al., 2020; Hornik et al., 2021; Bertin et al., 2020; Bierwiazczonek et al., 2020; Teovanović et al., 2020; Earnshaw et al., 2020). Also, information avoiding was affected by the spreading of rumors (Siebenhaar et al., 2020; Kim et al., 2020), as well as the adherence to anti-virus guidelines (Teovanović et al., 2020; Earnshaw et al., 2020).

In the meantime, the infodemic ruined the public trust in governmental and health institutions (Scerri and Grech, 2020; Taylor, 2020; Tapia, 2020; Hashmi et al., 2020; Basu et al., 2020). Editorials and commentaries from various journals, including *Lancet Infectious Diseases*, pointed out the avalanche due to the infodemic (*The Lancet Infectious Diseases* 2020; Lovari, 2020). Empirical studies showed that the infodemic and its manifestation—the conspiracy beliefs were negatively related to the trust in governments and organizations (Durodolu and Ibenne, 2020; Roozenbeek et al., 2020).

The infodemic also caused social problems—violence (Jolley and Paterson, 2020), misinterpretation of scientific data (Naeem and Bhatti, 2020; Patel and Nath, 2020), racism and xenophobia (Lima et al., 2020; Shimizu, 2020), cessation of public service (Depoux et al., 2020), as well as the increase of tobacco and alcohol usage (Luk et al., 2020). Finally, it caused the panic purchase on medical supplies for disease control and other merchandise (e.g., masks, gloves) (Tagliabue et al., 2020; Sandu, 2020; Williams et al., 2020), which further contribute to the economic turbulence (Hou et al., 2020).

### 3.3. Countermeasures of the infodemic

Various countermeasures were proposed against the COVID-19 infodemic, which were grouped into the following categories: countermeasure strategies for a low level of health /eHealth literacy, social media/mass media platforms, governments, and organizations, risk communication, and health information needs and seeking. The strategies for the low level of health literacy, for social media/mass media, and for governments and organizations were summarized in paragraphs since similar and general suggestions were found from different articles. In comparison, those for risk communication, health information needs were listed in tables since

concrete strategies were found in different articles, which makes the tabulation a better choice for presentation.

### 3.3.1. Countermeasures for the low level of health/eHealth literacy

Education and training programs were proposed as the strategies in this review. Education and training on health/eHealth literacy were required for the public communities or individuals to increase their ability to differentiate reliable information from the rumors. (Durodolu and Ibenne, 2020; Wormer, 2020; Mokhtari and Mirzaei, 2020; Mondiale de la Santé, 2020; Gottlieb and Dyer, 2020; Chou et al., 2021; Bastani and Bahrami, 2020; Vanderpool et al., 2020; Okereke et al., 2020; Schiavo, 2020; Morgan-Daniel et al., 2020; Alvarez-Risco et al., 2020; Chong et al., 2020; Cichocka, 2020; Scerri and Grech, 2020; Patel et al., 2020; Yu and Mani, 2020; Ahmed, 2020; Hui et al., 2020; Clark-Ginsberg et al., 2020; Vraga et al., 2020; Sharma et al., 2020; Xie et al., 2020; Dakhesh et al., 2020; Eysenbach, 2002; Graham, 2021; Morley et al., 2020; Vervoort et al., 2020; Sperry and Scheibe, 2002; Khan et al., 2020; Ratzan et al., 2020; Hartley and Vu, 2020) Empirical studies showed that an empowering intervention was able to significantly reduce the conspiracy beliefs among the public, hence reducing the spreading of rumors (van Stekelenburg et al., 2021; Richardson et al., 2020).

### 3.3.2. Countermeasures for governments and organizations

The strategies could be divided into two levels: governmental level and organizational level. For governments, they are suggested to be transparent, providing clear, honest information via official channels and accounts to the public to alleviate their anxiety and build their trust (Kulkarni et al., 2020; Casigliani et al., 2020; Horton, 2020; Looi et al., 2020; Peters, 2020; Dakhesh et al., 2020; Jaiswal et al., 2020; Erku et al., 2021). They are also responsible for monitoring the information flow on different platforms and fact-checking from a general perspective (King, 2020; Garcia and Duarte, 2020; Depoux et al., 2020). In addition, they are urged to take legal actions against the spreading of rumors [12,27.54,158,163,213,223-225]. For example, The Peru government enforced a prison sentence on anyone who created or shared false information, and similar movements were also witnessed in other countries (e.g., China, U.S., and India). Furthermore, they are also considered responsible for the coordination and collaboration among experts from different domains to fight against the infodemic (Khan, 2020; Basu et al., 2020; Lovari, 2020; Morley et al., 2020; Marwitz, 2021).

For organizations, they are responsible to provide accurate and up-to-date information for decision-making, consultation, and rumor refutation since they are the professional organizations fighting against the pandemic (JCIH Editorial Team 2020; Allahverdipour, 2020; Kulkarni et al., 2020; Sasidharan et al., 2020; Chou et al., 2021; Bastani and Bahrami, 2020; Casigliani et al., 2020; Lima et al., 2020; Looi et al., 2020; Hui et al., 2020; Khan et al., 2020; Erku et al., 2021; Marwitz, 2021; Tangcharoensathien et al., 2020; Kikuchi et al., 2020). For example, The WHO was reported to apply block chain technologies to addressing the surge of misinformation and Launching the EPI-WIN platform for rumor refuting (Kulkarni et al., 2020; Patel et al., 2020; Bernards et al., 2020). Also, medical professionals from these organizations are encouraged to make more presence on social media platforms to amplify their influence (Mheidly and Fares, 2020; Jindal and Anand, 2020; Hauer and Sood, 2020; Cuartas-Arias, 2020; Ingraham and Tignanelli, 2020; O'Connor and Murphy, 2020; Caulfield, 2020; Tomes, 2020; O'Connor and Murphy, 2020; Quadri et al., 2020). Besides, they are encouraged to understand the public health information needs and their information seeking, which was shown in detail in a later section (Zarocostas, 2020; Khan, 2020), and extend telemedicine service to alleviate patients' fear of being affected by attending physician's offices (Boakye et al., 2020).

### 3.3.3. Countermeasures for social/mass media platforms

As social media usage was identified as one major cause of the infodemic, these platforms are expected to take stricter censorship on

**Table 2**

Detailed countermeasures for public health information needs/seeking.

| No. | Recommendations for public health information needs/seeking  |
|-----|--|
| 1   | The infodemic is the product of a differentiated risk profile, suggesting that to address the infodemic is to tailor interventions to fit the various needs of different populations (Clark-Ginsberg et al., 2020; Chisita, 2020);   |
| 2   | To develop behavioral strategies to satisfy the needs of ethnic groups suffering the stigma and discrimination of disease (Patel et al., 2020);  |
| 3   | Governments should reach out to communities to ensure their information needs are understood, customizing messages to satisfy the audiences; craft texts for lay audiences (Bastani and Bahrami, 2020; Hauer and Sood, 2020; Xie et al., 2020; Tangcharoensathien et al., 2020; Hua and Shaw, 2020);   |
| 4   | Through EPI-WIN, WHO identifies the key "amplifiers," who are trusted sources of information for specific audiences, and by regular contact and discussion about their information needs, create appropriate informational and educational materials (JCIH Editorial Team 2020);   |
| 5   | Stop considering the current information that you are consuming. It is beneficial to consider everything as potentially being fake news unless you can verify them; Use common-sense questions to ask yourself when evaluating medical information[223] ;  |
| 6   | Find the right media documents, and ask the right questions (Sperry and Scheibe, 2002);  |
| 7   | The information from various sources should go through one dedicated center for them to decipher, diagnose, treat and inform affected individuals (Khan, 2020);  |
| 8   | Examine how people search and navigate the Internet for health information from the perspective of Infodemiology (Hernández-García and Giménez-Júlvez, 2020; Zhao et al., 2020; Sousa-Pinto et al., 2020; Rovetta and Bhagavathula, 2020; Eysenbach, 2009; Rovetta and Bhagavathula, 2020; Kopilaš and Gajović, 2020);   |
| 9   | Vet emerging sources for health providers and users in emergency (Morgan-Daniel et al., 2020);   |
| 10  | Taking a close look at the primary sources of information; reading in detail, not just the headlines; comparing data from different sources; checking where photos have been published before; searching for other posts or work by the same authors, and checking the publication date to provide more context (Alemañy-Castilla, 2020; Armitage et al., 2020); |
| 11  | Reduce the information overload and burden (Kearsley and Duffy, 2020);   |
| 12  | Discuss with friends with common sense; fact checking across different platforms; rely on official rebuttals of rumors (Zou and Tang, 2021).   |



the information related to the pandemic. (Zarocostas, 2020; Buchanan, 2020; Kulkarni et al., 2020; Marin, 2020; Rosenberg et al., 2020; Mheidly and Fares, 2020; Gottlieb and Dyer, 2020; Chou et al., 2021; Greenspan and Loftus, 2021; Scherer and Pennycook, 2020; Baker et al., 2020; Lima et al., 2020; Tasnim et al., 2020; Cuartas-Arias, 2020; van der Linden et al., 2020; Lovari, 2020; Sharma et al., 2020; Khan et al., 2020; Affelt, 2020; Rodrigues and Xu, 2020; Schillinger et al., 2020; Danilo et al., 2020; Pennycook et al., 2020; Ittefaq et al., 2020) Also, they are considered responsible for training their journalists with a high level of health/media literacy for science communication and reporting (Jamil and Appiah-Adjei, 2020). Besides, they are encouraged to take movements to alleviate the fears, depressions among the public, and exhaustion among the medical staff (Khan, 2020; Casigliani et al., 2020; Lovari, 2020); and spark empathy among the public for solidarity (Logie, 2020).

### 3.3.4. Countermeasures for public health information needs/seeking

The public health information needs and related health information seeking should be considered since meeting their information needs with adequate information will reduce their psychological issues, hence reducing their potential to spread the rumors. As the consumer health information needs are multidimensional, tailored health information and intervention strategies should be designed for different user groups (Okereke et al., 2020; Clark-Ginsberg et al., 2020; Pian et al., 2020; Chi et al., 2020). A list of concrete suggestions was found from this review, shown in Table 2.

### 3.3.5. Countermeasures for risk communication

An important category, risk communication strategies, surfaced from the review. Risk communication refers to building verbal/non-verbal structured messages in the minds of the target audience (Sezgin et al., 2020; Gallotti et al., 2020), which is aimed at alleviating the potential risks during the pandemic via risk assessment, intervention, and management (JCIH Editorial Team 2020; Mohamad, 2020). A list of concrete recommendations was found from this review, shown in Table 3.

## 4. Discussion

### 4.1. Summary of findings

It is the first time, during the COVID-19 pandemic, that the concern on the wide spreading of health-related rumors has been raised to the level of global health. From this review, social media usage and low level of health/eHealth literacy were found to be the major causes of COVID-19 infodemic. The vicious circle of rumor-spreading behavior and psychological issues from the public emerged as the characteristic of this infodemic. Besides, the fast publication process and preprint service were also proposed to foster the circulation of unverified or unreliable scientific results, which requires validation from empirical studies in the future. Other causes (e.g., health information needs/overloads, distrust of governments, and ideology) were also identified as possible causes. Countermeasures of the infodemic were recommended from different perspectives: for the low-level health/eHealth literary, governments and organizations,

**Table 3**  
Detailed countermeasures for risk communication.

| No. | Recommendations for risk communication   |
|-----|--|
| 1   | Strategies and processes of risk communication need to be implemented well in advance of an actual crisis; risk communication should be integrated into all aspects of the response, whether it is about tracing the contact or caring for the sick (JCIH Editorial Team 2020);  |
| 2   | Researchers should participate in media debates responsibly to disclose conflicts of interest, ensure accountability, and opt for an inclusive framing. The recognition and proper risk communication for uncertainty are also important to reduce fear mongering or risk underestimation (Kambakamba et al., 2020);   |
| 3   | Monitoring, infodemiology, infoveillance, and social listening (Eysenbach, 2020);  |
| 4   | Try to make those communications even better; risk communication research will lead to a way the population can understand (Garcia and Duarte, 2020; Biddlestone et al., 2020; Rahn, 2020);  |
| 5   | Pay attention to framing and content associated with message texts, including language, clarity, and ability to engage; origins of the information, including official and unofficial sources; features of the platform and its audiences; as well as the timing of messages; the volume of messages, including numbers of messages initiated and re-messaged; influence of amplifiers and detractors on platforms, including autonomous social media bots (Schillinger et al., 2020); |
| 6   | Interventions and messages must be based on science and evidence, enabling them to make informed decisions on protecting themselves and their communities in a health crisis; knowledge should be reorganized into actionable behavior-change messages, delivered in ways that are comprehensible and accessible to all individuals (Tangcharoensathien et al., 2020);   |
| 7   | Write down questions or rumors and go back to our risk communications colleagues, and then they help us find evidence-based answers (Zarocostas, 2020);  |
| 8   | Be honest to what you do not know; listen to the community with patience about their fears and perceptions; manage rumors and infodemic timely (Vaezi and Javanmard, 2020);  |
| 9   | Develop scales for risk assessment; (Chaitow, 2020; Chatterjee et al., 2020)   |
| 10  | Visual content should be designed or chosen with care to ensure the persuasiveness during the crisis (King and Lazard, 2020);  |
| 11  | Find influential accounts and names to fight against misinformation (Ahmed et al., 2020);  |
| 12  | Health messages need to be delivered in a calm and effective manner; use an empathic communicating style; design strategies for different groups of people based on their unique communication preference (Mheidly and Fares, 2020; Scerri and Grech, 2020);   |
| 13  | Control time on social media with related COVID-19 news, share stories of altruistic behavior and celebrate the work done by COVID-19 warriors; Stay away from social media and with family and friends and use face-to-face communication (Sasidharan et al., 2020; Pathak et al., 2020);   |
| 14  | Stop sharing bad news to patients and family members, and focus on the emotions, and use non-judgmental listening (Reddy and Gupta, 2020);   |
| 15  | Apply inoculation theory to the containment of misinformation (van der Linden et al., 2020);   |
| 16  | Ensure good information, safe access, critical assessment, a strong business model, and accountable institutions during the risk communication during the pandemic (Robie and Krishnamurthi, 2020).  |

social media and mass media platforms, public health information needs/seeking, and risk communication. The results are summarized in Table 4.

#### 4.2. Theoretical implications

Based on these findings, we proposed three theoretical implications. It should be noticed that our review focused specifically on the COVID-19 infodemic, which is an unprecedented global information crisis (Xie et al., 2020). Hence, the contributions may be limited to this unique event. Further research is required to test their applicability when extended to general misinformation scenarios.

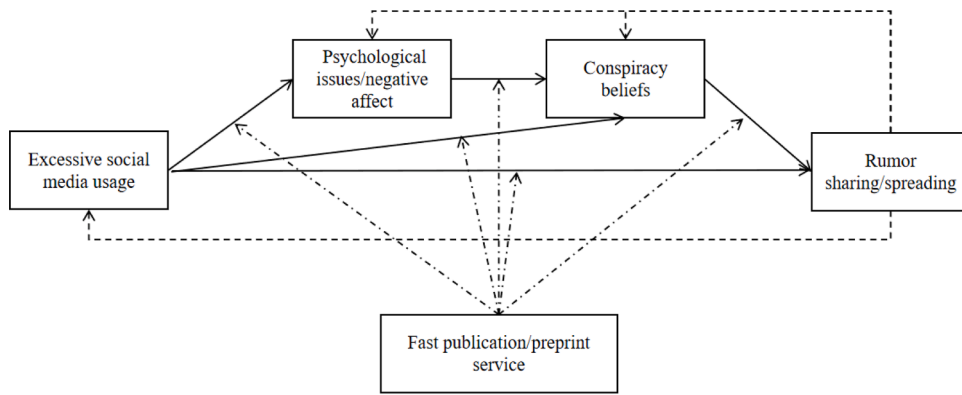
First, this review summarized possible psychological mechanisms from social media usage to the public's intention of sharing rumors, which was not thoroughly investigated by previous literature on human rumor sharing behavior. Social media usage was found to have a positive effect on the intention to share rumors during the infodemic (Apuke and Omar, 2020; Sun et al., 2020; Apuke and Omar, 2021), and its effect was mediated by the conspiracy and misinformation beliefs (Ahmed et al., 2020; Sun et al., 2020; Islam et al., 2020). Furthermore, the effect of social media usage on the formation of conspiracy beliefs was mediated by the psychological issues from the public (e.g., worry (Su, 2021)). Hence, a multi-mediated psychological path could be formed as social media usage → psychological issues from the public → conspiracy beliefs → rumor sharing. Additional mediated paths between social media usage and rumor sharing via any of the two mediators could be formed as well.

In comparison, previous research on rumor-sharing behavior focused on different perspectives. One theme of research took the perspective of information evaluation to understand rumor-sharing behavior. It was found that people tended to assess the perceived informativeness, credibility, and persuasiveness to estimate the perceived value of a message before deciding whether to share it (Pal et al., 2020). Similarly, other studies found that people evaluate the quality of the rumor (Koohikamali and Sidorova, 2017; Talwar et al., 2019) or the relevance of the negative information (Yin et al., 2020) before sharing. The information quality is a broad concept that involves a set of attributes (e.g., usefulness (Vakkari et al., 2019), credibility as mentioned above (Pal et al., 2020), sense-making to themselves (Marchionini, 2019; Zhang et al., 2020), and relevance (Pian et al., 2016)). This perspective conceptualized the rumor-spreading behavior as rational human behavior, as it purposely and systematically assessed the value within the rumor before deciding whether to share it (Talwar et al., 2019). Another theme of research took a hybrid perspective to combine the information evaluation as well as beliefs and emotions in characterizing the rumor-sharing behavior. They found that the message or information factors, belief, and emotional factors (e.g., perceived severity and perceived fear) worked synthetically in shaping the intention to share rumors (Chua and Chen, 2020; Laato et al., 2020). However, during the crisis, rumor sharing was found not affected by human authenticating behavior due to the time limitation (Talwar et al., 2020), which indicated that people might not have time or did not want to spend time evaluating the rumor systematically in that context. The negative relationship between systematic information processing and exposure to rumors was confirmed by another empirical study (Kim et al., 2020), suggesting a more important role of human psychological aspects in human rumor sharing during the infodemic. Hence, these two perspectives may not work well solely in explaining the rumor-sharing behavior during the infodemic.

The multi-mediated psychological perspective summarized in this review extended the belief and emotional factors from the hybrid perspective, as shown in Fig. 2. The two groups of mediators not only covered the perceived severity (Sun et al., 2020), negative emotions (e.g., anxiety and fear) (Sun et al., 2020; Islam et al., 2020), but also more specific and concrete psychological issues (e.g., distress, overload, and xenophobia) and various conspiracy beliefs (e.g., Vitamin C could cure the disease, and the virus came from military labs). Moreover, in the hybrid perspective, beliefs and emotions were antecedents of rumor sharing, which did not affect each other. In the multi-mediated perspective, the psychological issues affected the adoption of conspiracy beliefs (Su, 2021), which further contributed to the rumor-sharing behavior. Furthermore, social media served as merely the context for the two perspectives mentioned above. It was thought of as just a media platform/context where both the authentic information and the rumor were disseminated. However, it played as one factor in the multi-mediated perspective, contributing to the sharing of rumors (Apuke and Omar, 2020;

**Table 4**  
Summary of review findings.

| Result categories | Findings (for more details, please see the results section)   |
|-------------------|---|
| Causes            | Social media usage;<br>Low level of health/eHealth literacy;<br>The vicious circle of rumor spreading and public psychological issues;<br>Fast publication process & preprint service;<br>Others (e.g., ideology, health information needs and overloads, civil literacy, financial incentives and lack of supervision and trust)       |
| Impacts           | Public psychological issues;<br>Breakdown of trust;<br>Inappropriate protective measures;<br>Panic purchase;<br>Social problems (e.g., violence, racism and xenophobia)<br>Global economic recess;  |
| Countermeasures   | Countermeasure strategies for a low level of health /eHealth literacy;<br>Countermeasure strategies for social media/mass media platforms;<br>Countermeasure strategies for governments, and organizations;<br>Countermeasure strategies for risk communication;<br>Countermeasure strategies for health information needs and seeking. |



### Context: Pandemic/Public emergency

Fig. 2. The theoretical framework of the “vicious circle” of Infodemic.

Apuke and Omar, 2021).

Second, the two perspectives mentioned above were unidirectional, which suggested that the antecedents influenced the rumor-sharing behavior, but not vice versa. However, based on the findings of the review, the vicious circle of psychological issues and rumor-sharing behavior emerged. Social media usage during the infodemic was found to affect psychological well-being, which further contributed to the rumor sharing/infodemic via conspiracy beliefs. In return, the infodemic posed a negative impact on the public’s psychological well-being again (Bratu, 2020; Radwan et al., 2020; Dong et al., 2020; Gao et al., 2020; Sharov, 2020; Secosan et al., 2020; Siebenhaar et al., 2020; Marín et al., 2020), which exacerbated the rumor sharing (this could be achieved via or not via the other mediator-conspiracy beliefs, as proposed earlier). All these factors behaved in a cyclic manner, which was thought of as the characteristic of the infodemic, making the situation continually deteriorate, as we have observed. The vicious circle indicated the bidirectional effects among the factors in a temporal order, which furthered our understanding of the complexity of the infodemic dynamics.

Third, it may show compatibility with another stream of research on rumor dissemination—the virological approach (usually taken by computer scientists and mathematicians), compared to the behavioral approach mentioned above. It considers the rumor-sharing behavior as the virus infection in a network. Individuals are thought of as the nodes in the network and have chances to be infected by the rumor, similarly as infected by the virus. Susceptible-Infective-Removal (SIR) model and its variations (Jiang et al., 2020), together with mathematical simulations (or real-world datasets), are often used to depict the spreading patterns. These models assume a reciprocal infection process between nodes in the network (Jiang et al., 2021), suggesting that people could infect others via sharing rumors and be infected by exposure to others in the network cyclically. However, in these models, the individual susceptibility to rumors is often assumed subject to specific mathematical distributions, while reality may not be the case. By integrating the multi-mediated perspective, it could have a better estimation of the individual’s susceptibility, hence achieving better performance on prediction.

The multi-mediated perspective summarized from this review does not deny the applicability of the rumor-sharing models found in previous literature. It offered an extended view of human rumor-sharing behavior in this particular context, within which complex psychological paths with spiral-like interactions were suggested. It is beneficial to integrate it with other models to understand rumor dissemination in different contexts better. In addition, it might be possible that there are other mediators within the paths between the key variables mentioned in Figure 2 (e.g., high level of unmet health information needs and risk perception). The perceived risk perception may contribute to the high level of unmet health information needs and further to the psychological issues, which will exacerbate the perceived risk in a cyclic manner.

It is noticeable that the fast publication process and preprint service were also proposed as causes of the infodemic, but no empirical studies were conducted to confirm the relationship by now. The preprint service is similar to the social media platform where any manuscript could be uploaded and viewed by anyone else with free access. The dilemma of using preprint services was reported by the Science journal (Kaiser, 2017). It might be the case that certain manuscripts with unverified or fake scientific information will cause panic among the public, such as fear and anxiety, initiating the vicious circle as described above. However, further empirical studies are required to test the assumption. It is the same for the fast publication process.

#### 4.3. Practical implications

Based on the findings, we proposed three practical suggestions. First, the psychological well-being of the public and their beliefs should be taken care of simultaneously. It is our duty to provide accurate and reliable information to meet their information needs, as suggested by a call to action from information scientists (Xie et al., 2020). The psychological and belief factors also played an important role in determining people’s attention to share the rumor in a crisis. As the vicious circle suggests, we need to take action on both

stopping the spreading of rumors, mitigating the public's psychological issues, and correcting their conspiracy beliefs. It requires a holistic approach since focusing separately on each of them may fail to stop the circle from moving forward.

Second, it is noticed that a large group of concrete recommendations exist for risk communication. Risk communication studies investigate the effects of the communication strategies on reducing harmful psychological issues, as well as increasing public compliance with governmental policies (JCIH Editorial Team 2020; Schillinger et al., 2020; Pennycook et al., 2020). Given the variety of recommendations, there is a necessity to customize them for different groups of audiences. For instance, the elderly was suggested to stop consuming pandemic-related information as they were those highly vulnerable to rumors, and face-to-face communication was recommended instead (Affelt, 2020). Besides, different framing strategies should be considered for different groups of people as they may be only sensitive to particular messaging styles (Biddlestone et al., 2020).

Third, there is another large group of countermeasures for health information needs/seeking. Health information needs are the "knowledge gaps" to be filled with, which play an essential role in human information adoption and sharing (Pian et al., 2020; Chi et al., 2020). The level of satisfaction with health information needs was found negatively related to patients' anxiety (Møller et al., 2020; Kugbey et al., 2019; Stevenson et al., 2020). As their health information needs increase, people tend to become more anxious and uncertain, hence more likely to share rumors (Chi et al., 2020). Therefore, a multidisciplinary perspective should be taken to provide tailored health information for different groups of people, considering not only the customization of content but also the communication strategies mentioned above (Oh and Lee, 2019; Deng et al., 2015; Pang et al., 2020; Miwa et al., 2017).

Compared with the earlier review on COVID-19 misinformation mentioned in the introduction (Ali, 2020), more impacts were identified in this review (e.g., cession of protective behavior, abuse of alcohol and tobacco, and panic purchase), as well as the causes of infodemic. Furthermore, compared with another review article on general misinformation and social media from a business perspective (Di Domenico et al., 2021), the vicious circle of psychological issues and rumor-sharing behavior via conspiracy beliefs was summarized as the characteristic of the infodemic. Furthermore, countermeasures were provided in this review, offering what-to-do and how-to-do from different perspectives.

#### 4.4. Research limitations and future directions

Limitations of this review deserve attention. First, most empirical studies focused on finding the causes of the infodemic and were conducted in surveys or descriptive infodemological analyses of social media content. The majority of them received either three or four points in the rating of risk of bias (middle level of risk of bias), indicating that the potential bias of these research methods might not be ignored. The most frequent reasons for the bias were the sampling procedure (e.g., convenience sampling) and the representativeness of the samples (e.g., no justification of the representativeness). More experiments with representative samples are required in the future. However, similar findings were observed in different contexts and populations, suggesting that they may collectively hold a certain level of validity. Second, the bidirectional relationships between rumor-spreading behavior and public psychological issues emerged from the empirical studies, indicating the vicious circle of the infodemic. However, the two-way relationships were separately investigated.

Further investigation that integrates them within one model is required to validate the vicious circle in longitudinal studies. Third, the proposed countermeasures have not been tested; some were based on findings of empirical studies, but others on commonsense. It is important to validate them by empirical studies. Fourth, only articles written in English were included in this review. There should be articles written in other languages that are relevant to this topic. Since English is the international language for scholarly communication and publication, this review is supposed to cover the majority of the current literature on this topic. In addition, the number of relevant articles is expected to increase while this manuscript was written and reviewed. It may fail to include all the up-to-date literature, which is also the issue for all the systematic reviews. Notwithstanding these limitations, the findings from this review are still beneficial in providing a comprehensive picture of the current understanding of the infodemic.

## 5. Conclusion

Social media usage and low level of health/eHealth literacy were identified as the major causes of the infodemic. However, as possible causes for the infodemic, the fast publication process and preprint service were not reported in empirical research previously and deserved future investigation. Moreover, the vicious circle of infodemic, involving the interaction between rumor spreading behavior and psychological issues from the public, emerges as a characteristic of the infodemic, which is also new to us. Therefore, it is worth examining the spiral-like interactions between rumor-spreading and psychological issues and integrating it with models of rumor-sharing behavior from previous literature to provide a more comprehensive picture of this topic. In addition, it is important to investigate the social media "publications" (e.g., share, retweet) during the pandemic and their impacts on the infodemic when people have limited time and cognitive effort to respond. Furthermore, multidisciplinary empirical studies should be conducted to validate the effectiveness of these countermeasures, as even if the countermeasures seem logical, how effective they are when applied in different contexts (e.g., different geographic regions, user profile, social media platform, etc.) need to be investigated. It is the responsibility of researchers from all domains to work together against the infodemic.

### Contributor

WJ, JX and FC-Conceptualization. WJ and JX-Data curation, Formal analysis, Methodology, Investigation. WJ-Writing-original draft, review & editing, Funding acquisition. JX and FC-Writing-review & editing. FC- Funding acquisition, Project administration,

Supervision.

### CRedit authorship contribution statement

**Wenjing Pian:** Conceptualization, Data curation, Formal analysis, Methodology, Investigation, Writing – original draft, Writing – review & editing, Funding acquisition. **Jianxing Chi:** Conceptualization, Data curation, Formal analysis, Methodology, Investigation, Writing – review & editing. **Feicheng Ma:** Conceptualization, Writing – review & editing, Funding acquisition, Project administration, Supervision.

### Declaration of interests

We declare no competing interests.

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### Supplementary materials

Supplementary material associated with this article can be found, in the online version, at [doi:10.1016/j.ipm.2021.102713](https://doi.org/10.1016/j.ipm.2021.102713).

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