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Commentary

Infodemics: A new challenge for public health

Sylvie C. Briand,[1] Matteo Cinelli,[2] Tim Nguyen,[3] Rosamund Lewis,[4] Dimitri Prybylski,[5] Carlo M. Valensise,[6] Vittoria Colizza,[7] Alberto Eugenio Tozzi,[8] Nicola Perra,[9] Andrea Baronchelli,[10] Michele Tizzoni,[11] Fabiana Zollo,[2] Antonio Scala,[12,13] Tina Purnat,[3] Christine Czerniak,[1] Adam J. Kucharski,[14] Akhona Tshangela,[15] Lei Zhou,[16] and Walter Quattrociocchi[17,*]

[1]Global Infectious Hazards Preparedness Department, World Health Organization, Geneva, Switzerland
[2]Department of Environmental Sciences, Informatics and Statistics, Ca' Foscari University of Venice, 30172 Venice, Italy
[3]Impact Events Preparedness Unit, Global Infectious Hazards Preparedness Department, World Health Organization, Geneva, Switzerland
[4]Infodemic Management Group. Health Emergencies Programme, World Health Organization, Geneva, Switzerland
[5]Global Immunization Division, Center for Global Health, U.S. Centers for Disease Control and Prevention, Atlanta, GA 30030, USA
[6]Enrico Fermi Research Center, Piazza del Viminale, 1 — 00184, Roma, Italy
[7]INSERM, Sorbonne Université, Institut Pierre Louis d'Epidémiologie et de Santé Publique, IPLESP, Paris, France
[8]Multifactorial and Complex Diseases research Area, Bambino Gesù Children's Hospital, Rome, Italy
[9]Networks and Urban Systems Centre, University of Greenwich, London, UK
[10]Department of Mathematics, City University of London & The Alan Turing Institute, London, UK
[11]ISI Foundation, 10126, Turin, Italy
[12]Applico Lab, CNR-ISC, Roma, Italy
[13]Big Data in Health Society, Roma, Italy
[14]Department of Infectious Disease Epidemiology, London School of Hygiene & Tropical Medicine, London, UK
[15]Africa Centers for Disease Control and Prevention, African Union Headquarters, Addis Ababa, Ethiopia
[16]Public Health Emergency Center, Chinese Center for Disease Control and Prevention, Beijing, China
[17]Department of Computer Science, Sapienza University of Rome, 00185 Rome, Italy
*Correspondence: walter.quattrociocchi@uniroma1.it
https://doi.org/10.1016/j.cell.2021.10.031

The COVID-19 information epidemic, or "infodemic," demonstrates how unlimited access to information may confuse and influence behaviors during a health emergency. However, the study of infodemics is relatively new, and little is known about their relationship with epidemics management. Here, we discuss unresolved issues and propose research directions to enhance preparedness for future health crises.

Information in a disintermediated environment

The COronaVIrus Disease of 2019 (COVID-19) pandemic has shown the critical role of information diffusion in health emergencies and crisis management. The complexities of science knowledge and the scientific method are difficult to communicate to a broad audience—especially in light of heterogeneity in science literacy (Ruths, 2019). This context tends to yield extreme oversimplifications (e.g., zero risk/critical risk) that may polarize narratives. At the same time, the ongoing revisions of evidence and an overabundant and changing information landscape may induce confusion for policy-makers and civil society (Gallotti et al., 2020; Tangcharoensathien et al., 2020). For example, the problem of vaccine hesitancy seems to be related to an eroded trust in institutions fueled by misinformation spreading. Such a process has been called an information epidemic or "infodemic," and it is a clear example of how virtually unlimited online access to information may influence events unfolding in the physical world.

Our grasp of what an "infodemic" is and how it happens is still shallow and evolving. A possible reason for the mist around the term "infodemic" may reside in its very nature of an intuitive umbrella term that, however, includes many ramifications ranging from communication to epidemiology and that links to several open scientific debates such as that on misinformation spreading and its effects on society (Simon and Camargo, 2021). To be more specific, the term "infodemic," intended to mean an "epidemic of information," was introduced by Rothkopf (2003) to define the amplification effect of the news about severe acute respiratory syndrome (SARS) due to information technologies. A more recent definition of "infodemic" emphasized the element of misinformation spreading rapidly through social media platforms and other outlets (Zarocostas, 2020).

However, misinformation does not fully capture the complexity of the phenomenon, which seems to be strongly related to the evolving business model of information dissemination, currently dominated by social media (Cinelli et al., 2020). In light of this, "infodemic" was redefined as "an overabundance of information—some accurate and some not—that occurs during an epidemic" (Tangcharoensathien et al., 2020).

The uptake of an infodemic definition that does not directly tackle the concept of misinformation seems to point toward a bigger problem than the "true vs false" dichotomy, naturally limited by the fact that the concept of truth may differ across social groups. For this reason, other aspects related to human behavior, particularly the tendency of individuals to select information confirming their beliefs and ignore dissenting information (Del Vicario et al., 2016), should be taken into account to better understand the infodemic process. Indeed, it is reasonable to hypothesize that behaviors are important for infodemic development as much as they impact the epidemic sphere by

altering the chains of disease transmission (e.g., using masks, teleworking, and quarantining to reduce infection spread). However, it remains to be fully established the extent to which the infodemic affects behaviors that, in turn, may be relevant to the dynamics of pandemics. The apparent analogies between epidemics and infodemics have led to the suggestion that scientists and policy-makers can investigate, model, and monitor the two phenomena similarly (Scales et al., 2021).

Here, we argue that an infodemic, although intertwined with an epidemic, is a distinct phenomenon resulting from many interacting and overlapping processes such as the production, consumption, and amplification of (potentially harmful) information online. Thus, these processes' analogies, differences, and interplay must be considered to develop practical guidelines for managing and preventing future epidemics. This paper aims to spark discussions and collaboration to enhance preparedness for future health crises and improve the ability to anticipate the economic and social impact of policies put in place. We start by outlining analogies between epidemics and infodemics, as well as critical differences. Furthermore, we highlight the importance of considering them as mutually dependent and interacting phenomena also pointing out specific challenges for the future. Hopefully, a deeper understanding of the relationship between infodemics and epidemics will lead to insights that allow early prediction of epidemiological trends and effective management of communication during epidemic outbreaks and vaccination campaigns.

Analogies and differences

Information diffusion and social contagion processes are often characterized using epidemic or epidemic-inspired models, to the extent that rapidly sharing information is said to be "going viral." However, information and epidemic spreading also entail critical differences.

Agent

Epidemic. For epidemic processes of infectious diseases, the root cause is identifiable in a pathogen with certain biological features (e.g., infectious period, transmissibility, asymptomatic forms of infection) that spreads in a population through contacts between humans. During an epidemic, infectious agents belong to a single strain, although variants of the original agent may emerge over time.

Infodemic. For what concerns an infodemic, the agent is represented by a message broadcast in a given medium (e.g., a particular conspiracy theory in a viral video, a statistic on vaccine efficacy in a tweet). Such a message can appear in many forms depending on the communication channel and not necessarily be deceptive or harmful. Unlike the relationship between a pathogen and a host, the message is subject to the audience's interpretation and it can be perceived as hostile due to cognitive processes, misinterpretations, and the way it is presented on the medium.

Medium

Epidemic. For epidemics, the medium is represented by routes of transmission (e.g., respiratory, oral-fecal route, sexual contacts) whose involvement depends also on the pathogen which mainly drives prevention strategies.

Infodemic. In the case of infodemics, the medium is the communication channel. Conversely from the case of epidemics, the possible set of media able to fuel infodemic processes is constantly evolving with agents (messages) possibly navigating and mutating from medium to medium. Furthermore, while some media are subject to moderation that regulate their functioning some others are nearly impossible to monitor (e.g., dark web communities or closed online groups), thus making some routes of transmission essentially unobservable. Another subtle difference between epidemic and infodemic is the possibility of media platforms to tune the amount of information that one can retrieve both about them and about the agent under investigation. Two relevant examples are the case of Facebook narrowing the possibility to collect user data after the Cambridge Analytica issue or the case of Gab, an independent social media platform, accusing academics to smear their platform with a consequent downgrade of their API. Furthermore, due to phenomena such as media fragmentation, the user base can be extremely heterogeneous across communication channels as different media serve different purposes (exchanging opinions, watching the news, gaming) and entail a different level of attention to gather relevant information (watching TV versus reading a news article). Such a strong fragmentation of hosts for the pathogen across transmission routes seems to be more nuanced in the case of epidemics. Finally, while the number of routes of transmission is essentially open ended for the infodemic, it is not the case for epidemics (routes of transmission are neither infinite nor continuously evolving with the pathogen).

Timescale

Epidemic. The timescale depends on several factors, such as human behaviors relevant to the pathogen's transmission route, the pathogen's biological features, and the immune response of individuals. The evolution of an epidemic is usually made up of subsequent waves due to the accumulation of susceptible individuals over time. For example, according to simple Susceptible-Infected-Recovered-like models, epidemic waves take off when the basic reproductive number of the disease—a function of the features of the virus, the contact patterns, and the fraction of the population that is susceptible—surpasses the critical threshold. The infection of individuals, then transitioning to an immune or recovered state, leads over time to an epidemic wave, followed by a decreasing incidence of cases given a diminishing proportion of susceptible individuals. Beyond the natural evolution of an epidemic, waves may occur when population immunity is partial and public health measures are temporary. Upon the cessation of non-pharmaceutical public health interventions and social measures (Perra, 2021), susceptible population members are more likely to be exposed to the pathogen (Di Domenico et al., 2020).

Infodemic. At the moment of writing, the timescale of an infodemic is a key factor that still requires a *post hoc* investigation in order to be formalized. Nonetheless, previous studies displayed how the dynamics of information spreading are based on social contagion, the spread of ideas, attitudes, norms, or behavioral patterns from person to person through social influence, imitation, and conformity. Social contagion depends on users' attitudes, tendencies, intentionality, social

influence, and ties; therefore, its strength and duration are likely to depend upon several factors, such as pre-existing beliefs, polarization on a topic and its complexity, the extent to which information is considered reliable, and users' engagement. Considering such dynamics, the wavy evolution of an epidemic could be disregarded by the infodemic, whereas the production of new information regarding the disease could be continuous and potentially decoupled from epidemic waves.

Network of Interaction

Epidemic. The process of epidemic spreading relies on the patterns of contacts along which transmission occurs (individuals who have a connection are at risk for transmission). For epidemic processes, physical proximity and/or interaction with the agent or infectious hosts are required to transmit the disease by means of specific behaviors such as social gathering, sex, etc. Networks of interactions and average daily contacts may be heterogeneous across geographical areas (the higher the number of contacts in a time unit, the higher the velocity to develop and spread the infection), and non-pharmaceutical interventions can substantially reduce the density and frequency at which (new) links occur.

Infodemic. In the case of an infodemic, the transmission is remote and has no potential boundaries in terms of geographical scale. Furthermore, information spreading is becoming more and more rapid due to disintermediated communication and content production allowed by social media. Therefore networks of interaction, such as those underlying social media, are beyond any geographical boundary and reshape continuously around new topics with users segregating in echo chambers (where questionable information proliferates with more ease) and with recommendation algorithms that may reinforce shared narratives and foster individual polarization (Cinelli et al., 2021). Relatedly, the current technological infrastructure for information diffusion leaves room for strategic campaigns attempting to influence the information ecosystem (information operations) where certain agents may act as (super)spreaders (Ferrara et al., 2016).

Control measures

Epidemic. Depending on the availability of a vaccine, immunization campaigns and non-pharmaceutical interventions represent a milestone for controlling and possibly stopping disease epidemics. Furthermore, epidemiologic surveillance can be implemented efficiently to protect the risk categories and or contain outbreaks by guiding preventive interventions that may target specific population groups. In general, according to the biological characteristics of agents and route of transmission, several control measures can be implemented, such as isolating the source of infection and preserving individuals from contacts; protecting individuals through NPI; or implementing mass immunization or targeted immunization when the population at risk is clearly identifiable.

Infodemic. The case for immunization campaigns and immunity to an infodemic is less clear. Investing in building capacities for critical thinking (e.g., science literacy and media literacy) and other practices such as pre-bunking (Roozenbeek et al., 2020) may help to blunt an infodemic's negative impact. However, the potential impact of an "immunization strategy" in an infodemic, intended to encourage health-positive behaviors when facing polarization and conspiracy theories, is debated (Soveri et al., 2021). National or community-wide movement restrictions, and other public health measures such as isolation or quarantine, do not have a clear counterpart in the online realm, and equivalent restrictions may not have a similar effect. For instance, removing content or banning a user from a platform may be incompatible with respect to freedom of expression and makes it more difficult for public health teams to identify population concerns. Furthermore, strong moderation policies may cause mass migration on other platforms and thus result in unintended consequences such as further segregation and a rise of less regulated and monitored fringe communities.

Nonetheless, both infodemics and epidemics can be counteracted individually (for example through vaccination and skill-building) and collectively (through physical distancing and changing social norms). Protective behavior against outbreaks is associated with the notion of health risk, and individual behaviors and attitudes can vary due to risk perception. On the contrary, being exposed to an infodemic may not be perceived as a risk for personal health and safety or as a threat at all, despite posing a significant health risk.

The apparent analogies between epidemics and online infodemics are summarized in Table 1.

The interplay between infodemics and epidemics

While the interplay between information about the disease and disease propagation has long been identified as a key challenge in epidemiology, the infodemic during the COVID-19 pandemic is a clear example of how the information ecosystem and narratives may influence behaviors and public health outcomes. How the people perceive an epidemic may potentially impact choices that individuals, communities, and authorities make for infection prevention and control, with possible adverse effects such as:

- Authorities' delays in identifying, developing, and implementing effective and appropriate policies based on the best available information at the time. This is typical of "new" epidemics, where spread mechanisms can be very different from those of previously known outbreaks. Conversely, adopting appropriate policies leading to a substantial reduction of the infection rate may make people underestimate the seriousness of an issue. Early success might also lead people to disbelieve there was an actual issue or emergency to be addressed. Often, logical cause-effect links are lost.
- A community may reject policies and expert advice. This is more likely when an infodemic erodes trust in institutions, generally exacerbated by economic crises and rumors or misinformation. Acceptance of policies depends on a myriad of factors: identity, values, education, and more. Proper policies may eventually be perceived as inappropriate due to the infodemic process making the outcome of policy efforts, in the context of a

Table 1. The main analogies between epidemics and infodemics

Features	Epidemics	Infodemics
Agent	Infectious agent (i.e., virus, bacterium, fungus, parasite...)	Type of message in a given medium (e.g., particular conspiracy theory in a viral video, a statistic on vaccine efficacy in a tweet)
Medium	Route of transmission (respiratory, oral-fecal route, sexual contacts...)	Communication channel (news, social media platform, newsgroup, radio program, blog...)
Timescale	Infectious period, reproductive number	How quickly information spreads and accumulates, including the persistence of mis- and dis-information
Network of interaction	The pattern of contacts along which transmission occurs (individuals who have a contact at risk for transmission)	Communication network for the user and content interaction (nodes of transmission, interconnectedness, clustering, homophily, content filtering algorithms)
Control measures	Actions to limit the epidemic (vaccination campaigns, non-pharmaceutical interventions, epidemiological surveillance)	Actions to limit the infodemic (skill building, science and media literacy, pre-bunking)

dynamic society with lower resistance and resilience to misinformation, difficult to predict.

Beyond the initial perception of epidemics by authorities and citizens, which may reduce the effectiveness of the very first countermeasures from preventing epidemic spreading, infodemics may undermine vaccination campaigns.

Vaccinations have always been a central topic in mis- and disinformation environments, often related to conspiracy theories, and infodemics may increase the number of people believing in such theories, especially from the pool of individuals with low epidemics-related culture (e.g., low understanding of biological immunization mechanism, or mathematical effect of exponential growths), leading to less diffused immunization. Another issue is related to adverse events following immunization (AEFI), whose occurrence may lead to a negative hype about vaccine safety. Therefore, since information signals and trends may precede and foreshadow variations in vaccination coverage and incidence of vaccine-preventable diseases, the behavior of the time lag between these events is a field for further study. There is significant potential to develop social listening methods for openly shared information to feed into epidemiological surveillance and early warning systems.

Conclusions

The intersection between infodemics and epidemics represents one of the most critical areas for future studies to improve preparedness and population health globally. Indeed, social media radically changed the mechanism by which we access information and form our opinions. We need to better understand how individuals acquire or avoid information and how those decisions may influence their behavior. Despite the several projects and initiatives aimed at providing correct information to users, the impact of this information on personal choices is still an open issue.

Information consumption patterns may not necessarily be a reliable predictor of behavioral change. Instead, stronger activity on social media seems to result in further polarization. Henceforth, including the complexity of human behavior in epidemic management is of pivotal importance to address the many facets of this phenomenon through a scientifically grounded approach in order to support the design of effective communication strategies and develop the tools required to properly manage infodemics.

To reach this goal and capture the overall dimensions of epidemic/infodemic management, we substantially need an interdisciplinary approach involving epidemiologists, data scientists, physicists and mathematicians, risk communication practitioners, behavioral scientists, public health professionals, representatives of affected communities, and ideally support from the leading data providers (e.g., social media entities).

Along this path, to actuate timely responses to critical scenarios, the scientific community should identify the most suitable communication strategies and provide guidelines for journalists and stakeholders to communicate complex issues to a broader audience to avoid polarization. In turn, a communication effort should go in the direction of clarifying the roles of different stakeholder groups for a whole-of-society response. Even technical limitations have to be overcome with the aim of combining data and analytics and social sensing to promptly identify, fulfill, and eventually forecast social trends and information voids.

To summarize, in global pandemics, information shapes perceptions and may influence choices and thus policy design and social response. To enforce an improved epidemics surveillance, we should consider the contemporary presence of infodemics and epidemics dimensions, accounting for their singular and shared features.

ACKNOWLEDGMENTS

W.Q., A.B., and F.Z. acknowledge the 100683EPID Project "Global Health Security Academic Research Coalition" SCH-00001-3391. M.T. acknowledges the Lagrange Project of the ISI Foundation funded by CRT Foundation. S.B., R.L., T.N., T.P., and C.Z. are staff of the World Health Organization; D.P. is a staff member of the US Centers for Disease Control and Prevention; L.Z. is a staff member of the Chinese US Centers for Disease Control and Prevention. These authors alone are responsible for the views expressed in this paper, and they do not represent the views of their organizations.

DECLARATION OF INTERESTS

The authors declare no competing interests.

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