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The echo chamber effect of rumor rebuttal behavior of users in the early stage of COVID-19 epidemic in China

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ABSTRACT

During public health emergencies, as one of the most effective rumor management strategies, rumor rebuttals depend on users' cognition, decision-making and interactive behaviors. Taking the dissemination of rumor rebuttals related to COVID-19 epidemic in the early stage in China as an example, we firstly adapted network analysis to construct representative networks of information and communication flow networks of users based on users' retweeting and commenting behaviors. Then quantitative indicators and exponential random graph models were used to evaluate the level of homophily based on topic and veracity in information networks, identity and standpoint in user networks. Meanwhile, chi square tests were added to compare the degree of echo chamber effect in retweeting and commenting. Findings showed that, users did show significant echo chamber effect when retweeting or commenting on rumor rebuttal information with different veracity. They showed diversification when retweeting but a certain tendency and pertinence when commenting in topic selection. Weibo's direct and open platform for retweeting and commenting broke the boundaries between stakeholders from different professional fields. However, the retweeting mechanism promoted self-isolation of users' standpoints, while the commenting mechanism provided an understanding and integrating channel for groups with opposing standpoints.

1. Introduction

In the context of public health emergencies, online rumors have caused a temporary clamor. Due to the characteristics, namely participation, openness, communication, dialogue and community, of social media, such as Twitter and Weibo (a primary microblog website in China), the speed, breadth and depth of rumor spread have been increased (Zubiaga et al., 2016). Especially during COVID-19 epidemic, the spread of false information (such as "The Air Force of the Central Theatre District spread the disinfectant powder over Wuhan", "Citizens in Wuhan used high-concentration alcohol to disinfect indoors and caused fires", "5G was the cause of COVID-19 or it could accelerate the disaster's spread.") not only exacerbated the spread of panic, but also affected the public's correct understanding of scientific preventions, various conspiracy theories even became a stumbling block for the formation of a national anti-epidemic alliance (Wasim et al., 2020).

However, as a breeding ground for rumors, social media is also directly used for rumor management. Relevant organizations, including the police and official media, have published hundreds of accounts on Weibo to help distinguish rumors and release rumor rebuttal information (Cao & An, 2011). General public also actively participate in the rumor suppression practice (Zeng et al., 2019). Unfortunately, the above actions are not entirely effective for the following reasons. Some rumor rebuttal information released by public lacks fact-checking. National media or government agencies even make up new rumors to refute the old ("refute rumors with rumors") to cover up scandals or underestimate the casualties caused by the crisis (Wen & Huang, 2015, pp. 81–87), which severely undermines the public's trust in the authority of rumor rebuttal information, conversely deepening their trust in rumors and triggering "backfire effect" eventually (Petrova & Cialdini, 2005).

Social media can offer access to an unprecedented amount of content, and the direct channels from content producers to information

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consumers have changed the way users obtain information, debate and shape their views (Michela et al., 2016). Communication has become increasingly personalized, both in the way messages are framed and how they are shared across social networks (Schmidt et al., 2017). Recent studies have shown that online users tend to focus on specific narratives which conform to their worldview (even if pieces of content are deliberately false (Bessi et al., 2014; Mocanu et al., 2015)) and dismiss information unrelated or contradictory to their worldview (Zollo et al., 2017) to form an echo chamber, which has profoundly affected social issues such as policy dissemination (Guo et al., 2020; Tsai et al., 2020), public debate (Schmidt et al., 2018; Williams et al., 2015) and rumor governance (Wang & Song, 2020). In the spread of rumor rebuttal information related to public health emergencies, although this kind of information environment can meet the personalized information need and save the cost of obtaining information. Being trapped in the inertia of selective exposure by one and one's neighbors in the social network might narrow the information sources of users and block the normal communication between different groups (Wang & Song, 2020). The accompanying cognitive defects and narrow biases might lead to group polarization and social fragmentation, eventually causing the invalidation of the guidance for rumor rebuttal (Zhang, 2020). The key to solving this problem is to pay attention to the echo chamber in rumor rebuttal discussion, only after making sense of the relationship between which and the information consumption/social interaction of users on social media, can we provide urgent insights about rumor rebuttal strategies for public opinion managers from the perspective of users' comprehensive access to information and the prevention of group polarization.

2. Related work

2.1. The effectiveness of rumor rebuttals

Rumor refers to the information widely circulated without confirmation to alleviate fear and anxiety under uncertain or dangerous information situations (DiFonzo & Bordia, 2006; Jung, 1909). Rumor rebuttal is a kind of anti-rumor persuasion behavior, and its essence is to produce correct information to effectively counteract the spread of rumors (Xiong, 2012). According to the persuasive information model (Hovland & Weiss, 1951), the characteristics of rumor rebuttal source (Berinsky, 2011; Bordia et al., 1998, 2005; DiFonzo & Bordia, 2000; Esposito & Rosnow, 1983; Tang & Lai, 2018; Wang et al., 2013, pp. 2–8; Zeng et al., 2019; Zeng & Wei, 2016, pp. 25–34), content (Chen et al., 2017; Ruan & Xia, 2020), communication channels (Chen, 2020, pp. 2–11; Huang, 2020), and information receivers (Nyhan & Reifler, 2010) significantly affect the effectiveness of rumor rebuttals. In disaster events, government is the main force (Wang et al., 2013, pp. 2–8) and media is the backbone (Zeng & Wei, 2016, pp. 25–34). Limited researches also shifted attention to other subjects, such as general public, civil organizations (Zeng et al., 2019). Chen et al. (2017) found that the topic, originality, number of pictures and “@” significantly affected the number of retweets, while the topic, originality, way to refute rumors, emotional intensity and content length significantly affected the number of comments. Ruan and Xia (2020) divided the ways to refute rumors into “direct refutation” and “indirect refutation supplemented by truth statement”. This classification strategy obviously assumed the rumor rebuttal having been verified and true, but ignored the false side of it. Therefore, this study, analogous to Wang and Song (2020) on the definition of rumors' veracity, proposed another way to classify the rumor rebuttal's veracity (“refute rumors with truth”, “refute rumors with rumors”, and “refute rumors with doubts”). A few researches pointed out that different individuals had different perceptions of the credibility or importance of information based on their own needs, interests, and values. They tended to trust information that conformed to their original standpoints (Nyhan & Reifler, 2010).

2.2. The form and degree of echo chamber effect

Echo chamber refers to the situation or environment where heterogeneous information/opinions cannot enter the personal information world due to the individual's psychological tendency of selective approach/avoidance, which means that users tend to only share/exchange information/opinions which meets their own relatively solidified single interest, preference and belief, or with whom share the same interest, preference and belief to reinforce their existing shared worldviews (Dubois & Blank, 2018). Bruns (2017) pointed out that the existence of clusters in social networks was understood as the evidence of echo chamber where nodes tended to preferentially connect to nodes in clusters and form homogeneous communities. Homophily meant that “the contact probability between similar nodes was higher than that between dissimilar nodes” (Hemelboim et al., 2013). Some research found highly isolated homogeneous communities on social media (Bessi et al., 2014; Medaglia & Yang, 2016; Schmidt et al., 2017), while others showed that viral information on social media could penetrate into different communities (Weng et al., 2013). The latter argued that several studies exaggerated the extent to which social media users deliberately avoided expressing objections on Internet (Holbert et al., 2010). Compared with offline networks, online networks could achieve diversified information disclosure and weaken interpersonal ties (De Meo et al., 2013), so users were more likely to encounter novel ideas than those frequently seen in closely connected social circles (Kim et al., 2013).

Researches related to echo chamber used different social network construction approaches in different situations to model users' behaviors (retweeting, commenting, and mentioning), and obtained different conclusions about the form and degree of echo chamber effect based on different nodes' attributes. Wang and Song (2020) established a representative network of information and a communication flow network of users based on users' commenting behavior. Combined with the low level of homophily based on rumors' veracity in the information network, and the mix of homogeneity and heterogeneity based on users' attitudes in the user network, they concluded that the echo chamber effect in discussions on genetically modified rumors on Weibo was unobvious, specifically, on the one hand, users tended to comment on both true and false rumors; on the other hand, some users who supported rumors only commented on users who supported rumors, but there were also some users who supported rumors commented on users holding different attitudes. Bessi et al. (2014) and Schmidt et al. (2017) used similar methods to construct information representative networks, which proved the echo chamber effect in users' selecting information's topics. The former indicated that conspiracists preferred topics based on conspiracy rather than science, the latter characterized the news consumption patterns of users on Facebook, and discovered that each user tended to focus on a limited set of pages with relatively fixed and similar topics. Zhang and Ho (2020) draw lessons from the principle quoted in Bibliometrics, according to the retweeting behavior of the third-party users, established a network of retweeted users, and concluded that the performance of data-driven journalism in electronic public domain had broken the boundaries between people from different professional field. Tsai et al. (2020) constructed three user interaction networks (communication flow networks) based on users' retweeting, mentioning and commenting behaviors. In the context of political consumers' rights protection, they revealed the prominent performance of ideological echo chamber in the retweeting and mentioning networks, and the highly mixed user groups with opposing political views in the commenting network. They explained that retweet expressed the will to increase the visibility of a given information, mention was used to call out to specific like-minded peers to accomplish collective goals (both retweet and mention served to share information with one's followers and specific audiences), but comment was the way in which online collective debates took place around the original posts. Guo et al. (2020) merged retweeting and mentioning relationships, and investigated the

echo chamber on Twitter based on users' standpoints on candidates in retweeting and commenting during the 2016 US presidential election.

2.3. Research questions

Researches on the effectiveness of rumor rebuttals mostly analyzed from the information publishers' perspective, such as the characteristics of publishing source, content and channels. They ignored or simplified the specific transmission process of rumor rebuttal in online networks and the information receivers' selective acceptance behavior. Researches on echo chamber effect mainly focused on the controversial and widespread social problems, but rarely focused on rumor governance especially during public health emergencies. As the opposite of rumors, rumor rebuttals were still controversial in the dynamic game process with rumors (Goh et al., 2017). This study attempted to explore whether echo chamber effect existed in the cognition, decision-making and interaction behaviors of users when participating in the rumor rebuttal discussion on Weibo, and clarify its form and degree. The performance of echo chamber varied with types of social networks (representative networks, communication flow networks), feature dimensions (information's topic, veracity, and user's professional-field and standpoint attributes) and interaction mechanisms (retweeting, commenting). To guide that trajectory of our research, we devised the following research questions.

RQ1. When users retweeted or commented on rumor rebuttal information related to COVID-19 on Weibo, was there echo chamber effect in topic/veracity selection? What was the degree of exposure? Was it significantly different in users' retweeting and commenting behaviors?

RQ2. Did the users who participated in retweeting or commenting on

rumor rebuttal information related to COVID-19 on Weibo break the echo chamber of identity/standpoint? What was the degree of cross-identity/anti-standpoint interaction? Was it significantly different in users' retweeting and commenting behaviors?

3. Methods

The research design was shown in Fig. 1.

3.1. Data collection and preprocessing

In the early morning on January 23, 2020, Wuhan officially announced that the city's bus, subway, ferry and long-distance passenger transportation would be suspended from 10 a.m., and the closure of Wuhan would begin. It was not until midnight on April 8, 2020, that Wuhan announced its unblocking. Facing the sudden health crisis, absence of the key official information led to an information vacuum (Shibutani, 1966). Public sought information more intensely than ever as health issues required unfamiliar expertise and dealt with life-and-death problems. The increase in fear and uncertainty made public more vulnerable to rumors. During this period, attention and actions for rumor rebuttals were extremely significant. Firstly, using the keywords "novel coronavirus/COVID (新冠)" and "rumor rebuttal (辟谣)", Sina Weibo API was called to obtain the original tweets of rumor rebuttals and their posters' information from 10 a.m. on January 23, 2020 to midnight on April 8, 2020. Then, it traversed the retweeting and commenting lists of each original tweet, and crawled the tweets and user information of retweeting/commenting. A total of 3446 original tweets were initially obtained, corresponding to 23,858 retweeting tweets and 12,740 commenting tweets. Next, we invited two trained professionals

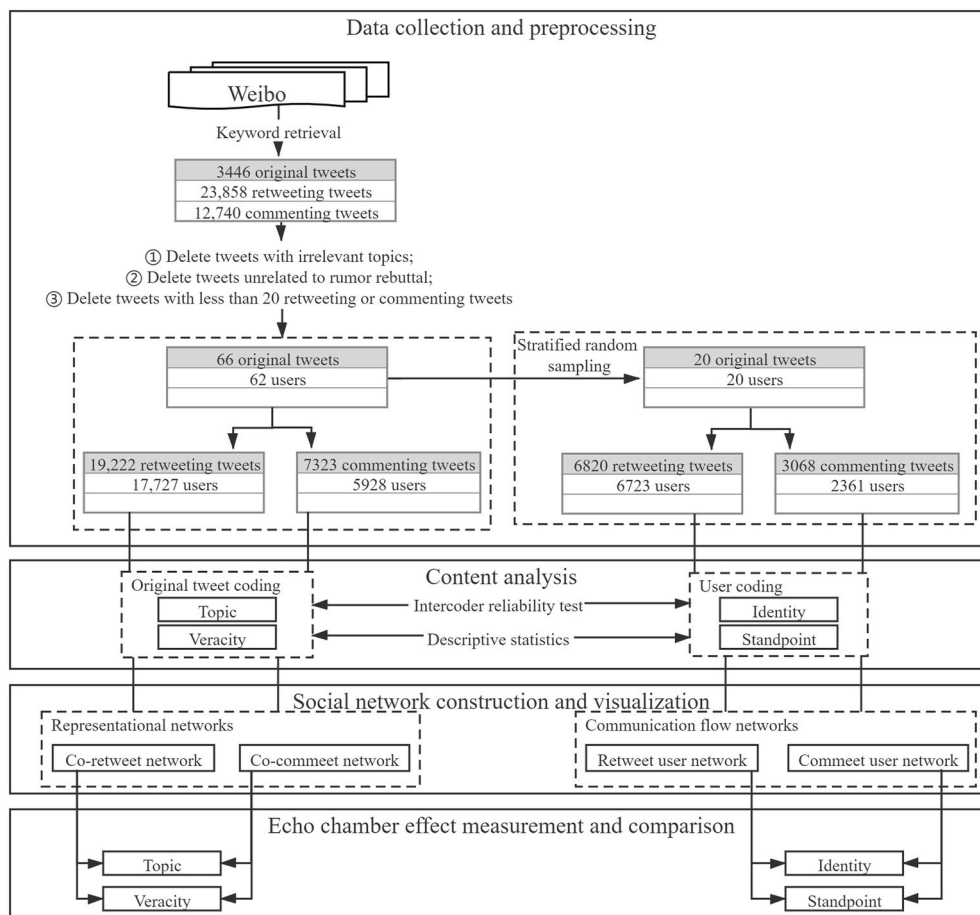


Fig. 1. Research design.

to annotate the 3446 original tweets. If it talked about unrelated topics or did not aim to refute rumors, it was coded as ‘N’; if not, it was ‘Y’. The coders conducted the intercoder reliability test (Krippendorff, 2011) based on the 10% of sample data ($\kappa = 0.887$). After eliminating differences and reaching agreement through discussion, they marked the remaining samples. We deleted 29 original tweets coded as ‘N’, and 3351 original tweets whose retweeting or commenting volume less than 20 to exclude the samples with low influence (Wang & Song, 2020). Remained 66 original rumor rebuttal tweets contrasted with recognized rumors, corresponding to 62 posters, 19,222 retweeting tweets corresponding to 17,727 users, 7323 commenting tweets corresponding to 5928 users.

3.2. Content analysis

3.2.1. The topic of rumor rebuttal information coding and definition

Rumors belonging to different topics reflect the public’s information needs, and the rumor rebuttal under corresponding topics represent the targeted clarification and guidance of rumors by anti-rumor subjects. To guarantee the integrity of topic coding, the two coders referred to the rumor rebuttal’s topic classification related to COVID-19 epidemic in the research of Chen (2020, pp. 2–11), and annotated the topics for 3417 original tweets (after excluding 29 unrelated tweets). The coders conducted the intercoder reliability test based on the 10% of sample data ($\kappa = 0.925$). After modifying and deleting several categories in the coding process, repeatedly reviewing and eliminating differences, they finally determined 10 topic categories, shown in Table 1, according to which, they marked the remaining samples. Topics of the selected 66 original rumor rebuttal tweets could be found.

3.2.2. The veracity of rumor rebuttal information coding and definition

Independent of topic coding, follow the same process, the original tweets were divided into three veracity categories: “refute rumors with truth” (refute rumors by telling the truth), “refute rumors with rumors” (fabricate new rumors in the name of refuting rumors), “refute rumors with doubts” (refute rumors with uncertainty, that is, put forward questions while publishing rumor rebuttal information) ($\kappa = 0.917$). Examples are shown in Table 2. To determine veracity, coders needed to collect knowledge from multiple authoritative sources, such as: Weibo Community Management Centre’s “false information” column (Zeng et al., 2019), Tencent real platform (Chen, 2020, pp. 2–11), WeChat official account (“Dr.Lilac” (“丁香医生”), “Popular Science China” (“科普中国”)) (Jin & Xu, 2020)).

3.2.3. The identity of users coding and definition

To simplify the complexity of users’ networks and mine the community structure of users, we randomly selected 20 original rumor rebuttal tweets from the 66 original tweets by stratified sampling. Then the identities of the original posters and users participating in retweeting and commenting were coded. Referring to the stakeholders’

Table 1
Topic categories of rumor rebuttal information.

| Topic categories | Explanation |
|-------------------------------------|--|
| Virus | The pathological characteristics, name of virus, etc. |
| Contagion | The infection ways of the disease |
| Preventions | The prevention knowledge of the disease |
| Patients | The physical and mental health of the patients |
| Sequelae | The sequelae in recovered population |
| Epidemic situation | The spread of the epidemic in various regions |
| Domestic government countermeasures | Countermeasures of government in China |
| Domestic other countermeasures | Countermeasures of organizations (not including government) in China |
| Foreign countermeasures | Countermeasures of countries outside China |
| Other | Other topics |

Table 2

Examples of veracity coding of rumor rebuttal information (translated from Chinese).

| Veracity categories | Rumor | Rumor rebuttal information | Notes |
|---------------------------|---|---|--|
| Refute rumors with truth | Drinking alcohol of high concentrations can resist coronavirus [Unconfirmed] | #Weibo rumor rebuttal# Academician Li Lanjuan, a member of the high-level expert group of the National Health Commission, said that 75% of medical alcohol could effectively inactivate the virus, but it could only be used for body surface disinfection. If drinking into the body, it would be absorbed and metabolized, and would not affect the virus. [Confirmed] | |
| Refute rumors with rumors | Cats and dogs are susceptible to the novel coronavirus. [Unconfirmed] | [Important rumor rebuttal] There is no evidence that cats and dogs will be infected with the novel coronavirus. Please be kind to your pets! [Unconfirmed] | In fact, the researchers found some infected pets after sampling in the houses of survivors and the pet hospitals. [Confirmed] |
| Refute rumors with doubts | Starting from March 2, 2020, universities will start classes in batches. [Unconfirmed] | #Education Bureau rumor rebuttal # Is it true that school starts on March 2? But the Education Bureau has refuted the rumors? | |

classification in public health emergencies by An et al. (2018), we supplemented and deleted some categories during the coding process. Finally, the codebook was determined as 7 categories and 17 sub-categories, shown in Fig. 2. The two professionals marked each user’s identity according to the items such as “user name”, “authentication description”, “industry category”, “geographical location”, “graduated school”, “work company” and “introduction”. After testing the intercoder reliability based on 10% user sample data (Krippendorff, 2011), discussing eliminating differences and reaching an agreement, they continued to mark the remaining samples (retweeting users: $\kappa = 0.933$; commenting users: $\kappa = 0.966$).

3.2.4. The standpoint of users coding and definition

Independent of the identity coding, users’ standpoints were divided into four categories: “agree” (agree with the rumor rebuttal), “disagree” (deny the rumor rebuttal), “query” (ask for more details about the rumor rebuttal), “unknown” (not clearly indicate their standpoints) (Ma & Luo, 2020). Certain researches treated retweeting as a sign of approval (Li et al., 2021). But in fact, when users retweet the original content, they will also add their own additional ideas. Therefore, for each original poster, if the veracity of original rumor rebuttal tweet was coded as “refute rumors with doubts”, then the poster’s standpoint was marked as “query”, otherwise, “agree”. For each retweeting user, we firstly determined the user’s standpoint expressed in a single retweeting tweet, then comprehensively considered all the retweeting tweets from the user, and selected the standpoint with the highest frequency of expression as the user’s common standpoint (“agree”, “disagree”, “query”). If there was frequency juxtaposition, the standpoint expressed by the latest retweeting tweet shall prevail. If all the retweeting tweets of the user did not express standpoints clearly, then the user’s standpoint was

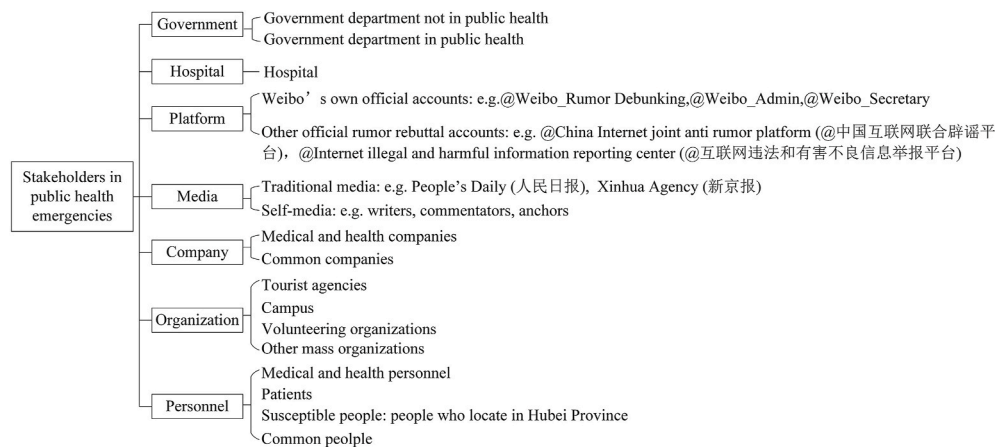


Fig. 2. Classification of stakeholders' identities in public health emergencies.

“unknown”. For each commenting user, we made annotation following the same rule. Doing the intercoder reliability test based on 10% user sample data (Krippendorff, 2011), after the discussion to eliminate differences and reach an agreement, the remaining samples were marked (retweeting users: $\kappa = 0.857$; commenting users: $\kappa = 0.898$).

3.3. Social network construction and visualization

3.3.1. Representational networks of rumor rebuttal information

Based on 66 original rumor rebuttal tweets and their retweeting and commenting data, we first established two affiliation networks based on retweeting and commenting to map the relationship between two types of nodes: one referred to original rumor rebuttal tweets, the other referred to users (Faust, 1997). Then we transformed the two two-mode affiliation networks into two corresponding single-mode representational networks. In the co-retweet network, if a user retweeted the original tweet i and j , then there was a connection between the original tweet i and j . In the co-comment network, if a user commented on the original tweet i and j , then there was a connection between the original tweet i and j . The two networks of original rumor rebuttal tweets were both undirected and weighted.

We used NetworkX package of Python to construct these two information representative networks (Hagberg et al., 2008), and obtain the detailed topological structure features. Finally, the chord diagram visualization of Echarts (Li et al., 2016) was used to visually display the degree of homophily based on the topic and veracity in the networks of original rumor rebuttal tweets.

3.3.2. Communication flow networks of users

Communication flow relations refer to the exchange or transmission of messages among individuals (Shumate et al., 2013). Based on the 20 original rumor rebuttal tweets and their retweeting and commenting data selected in section 3.2.3, two user networks were constructed respectively. In the retweet user network, if user i retweeted a tweet from user j , there was a connection from i to j ; in the comment user network, if user i commented on a tweet from user j , there was a connection from i to j . The two communication flow networks of users were both directed and weighted.

NetworkX package was also used to establish the two user networks, from which relevant features could be extracted (Hagberg et al., 2008). We next used Gephi to visualize the degree of homophily based on users' identity and standpoint, and its Fruchterman Reingold layout algorithm to visualize the connectivity in user networks (Fruchterman & Reingold, 1991).

3.4. Echo chamber effect measurement and comparison

We firstly counted the connection frequency of nodes with similar or different attributes (topic/veracity in representational networks of information, identity/standpoint in communication flow networks of users), and roughly considered the high connection frequency between similar nodes and/or the low connection frequency between different nodes as evidence of homophily (Guo et al., 2020; Tsai et al., 2020; Wang & Song, 2020). Furthermore, we estimated the exponential random graph models (ERGMs) performed by the “nodematch” function by the Statnet suite of packages available on the Comprehensive R Archive Network to detailly examine the homophily effects among the tie-formation process of nodes with a similar attribute (Goodreau et al., 2008).

4. Results

4.1. Descriptive statistics

In Fig. 3 (a), during COVID-19 epidemic, the rumor rebuttal about the epidemic spread reached 50.00%, the prevention knowledge reached 12.12% and the infection ways/countermeasures of the Chinese government and overseas countries all reached 7.58%. In Fig. 3(b), tweets mostly refuted rumors based on facts, some subjects raised questions while publishing rumor rebuttal information, and minimal subjects clarified the original rumors by creating new rumors.

In Table 3, most of the users who participated in retweeting the 20 original rumor rebuttal tweets were common people (86.92%), followed by self-media (6.21%), susceptible people (3.51%), government departments not in public health (1.33%), common companies (0.71%) and traditional media (0.58%). Users who participated in commenting, most were common people (90.84%), followed by self-media (4.66%), susceptible people (3.15%). Government departments (0.21%), traditional media (0.34%) and hospitals rarely participated in commenting. Medical companies and patients were not identified in retweeting and commenting user collections.

In Table 4 most of the retweeting users agreed with the rumor rebuttal (92.01%), the minority still believed in rumors (5.22%), and the smaller part sought more information about the rumor rebuttal (2.06%). In commenting, users mostly showed denial, doubt or ambiguity.

In Fig. 4, compared to retweeting, apart from government departments, Weibo's official accounts and official rumor rebuttal accounts, the standpoints of users with other identities in commenting were more diversified. It was worth noting that a few accounts belonging to government public health departments and traditional media retweeted or commented to express their objections and doubts towards rumor rebuttals.

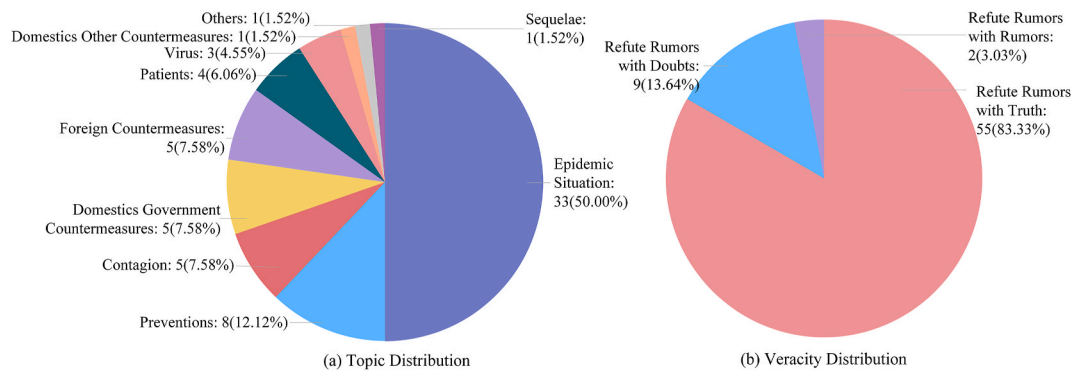


Fig. 3. Topic (a) and veracity (b) distribution of original rumor rebuttal tweets.

Table 3
The distribution of users' identities.

| Identity categories | | Retweet user network | Comment user network |
|---------------------|--|-----------------------|-----------------------|
| Government | Government department not in public health | 90(1.33%) | 5(0.21%) |
| | Government department in public health | 8(0.12%) | 0(0.00%) |
| Hospital | Hospital | 4(0.06%) | 0(0.00%) |
| Platform | Weibo's own official accounts | 1(0.02%) | 1(0.04%) |
| | Other official rumor rebuttal accounts | 7(0.10%) | 1(0.04%) |
| Media | Traditional media | 39(0.58%) | 8(0.34%) |
| | Self-media | 419(6.21%) | 111(4.66%) |
| Company | Medical company | 0(0.00%) | 0(0.00%) |
| | Common company | 48(0.71%) | 11(0.46%) |
| Organization | Tourist agency | 6(0.09%) | 2(0.08%) |
| | Campus | 9(0.13%) | 0(0.00%) |
| | Volunteering organization | 4(0.06%) | 2(0.08%) |
| | Other mass organization | 5(0.07%) | 0(0.00%) |
| Personnel | Medical and health personnel | 5(0.07%) | 2(0.08%) |
| | Patient | 0(0.00%) | 0(0.00%) |
| | Susceptible people | 237(3.51%) | 75(3.15%) |
| | Common people | 5861(86.92%) | 2163(90.84%) |
| Total | | Original users:20 | Original users:20 |
| | | Retweeting users:6723 | Commenting users:2361 |

Table 4
The distribution of users' standpoints.

| Standpoint categories | Retweet user network | Comment user network |
|-----------------------|-----------------------|-----------------------|
| Agree | 6204(92.01%) | 914(38.39%) |
| Disagree | 352(5.22%) | 399(16.76%) |
| Query | 139(2.06%) | 350(14.70%) |
| Unknown | 48(0.71%) | 718(30.15%) |
| Total | Original users:20 | Original users:20 |
| | Retweeting users:6723 | Commenting users:2361 |

4.2. Network structure and echo chamber effect in information networks

Compared with the co-comment network, the co-retweet network was smaller but denser. It consisted of 66 nodes and 1398 edges (density = 0.65, average weighted degree = 111.818), while the co-comment network contained 66 nodes and 86 edges (density = 0.04, average weighted degree = 8.121).

4.2.1. Echo chamber effect performance from topic dimension

In Fig. 5, the outer ring of ten different colors represented a

collection of ten different topics of original rumor rebuttal tweets, the arc length represented the total connection volume of all the original tweets belonging to this topic, and the internal colorful connecting bands indicated the flow direction and order of magnitude of data relations. In co-retweet network, the top three topics which interacted most frequently with others were "Epidemic situation", "Preventions" and "Patients". "Epidemic situation" was often retweeted by users with the topics such as "Preventions", "Patients", "Foreign countermeasures", and "Domestic government countermeasures" at the same time. Besides, "Patients" was usually associated with "Preventions". In co-comment network, compared with other topics, the internal connection of "Epidemic situation" was more obvious. Fig. 6 showed that in co-retweet network, the number of connections between the same topic only accounted for 19.51% (n = 720), and the number of connections between different topics accounted for 80.49% (n = 2970). But in co-comment network, the corresponding two proportions were 75.75% (n = 203), 24.25% (n = 65) respectively. The chi-square test results claimed that the proportion of like-topic connections among the original tweets in co-comment network was significantly higher than which in co-retweet network. Table 5 indicated that the nodes of the original tweets belonging to a certain topic would be more likely to establish a link with another node belonging to the same topic in co-comment network (coefficient = 1.481, p < 0.001). However, this was not the case in co-retweet network (coefficient = -0.781, p < 0.001). As a result, the users did not have a significant echo chamber effect in topic selection when retweeting rumor rebuttal information, while users' commenting was topic-specific.

4.2.2. Echo chamber effect performance from veracity dimension

In Fig. 7, the outer ring of three different colors represented three interactive sets of original rumor rebuttal tweets based on veracity classification. Fig. 8 homophily measurement showed that in co-retweet network (co-comment network), the number of connections between the same category accounted for 87.67% (n = 3235) (77.99% (n = 209)), far exceeding the number of connections between different categories. The chi-square test results claimed that the proportion of like-veracity connections among the original tweets in co-comment network was significantly lower than which in co-retweet network. Table 5 indicated that only the original tweets which refuted rumors with truth were significantly more likely to be co-retweeted with other original tweets which refute rumors with truth (coefficient = 0.264, p = 0.009). The original tweets which refuted rumors with rumors were also more likely to be co-retweeted with other original tweets which refute rumors with rumors, but not significantly (coefficient = 11.883, p = 0.971). The similar phenomenon also occurred in refuting rumors with truth for commenting (coefficient = 0.004, p = 0.986). Considering the above results, there was a significant echo chamber effect when users retweeted or commented true rumor rebuttals.

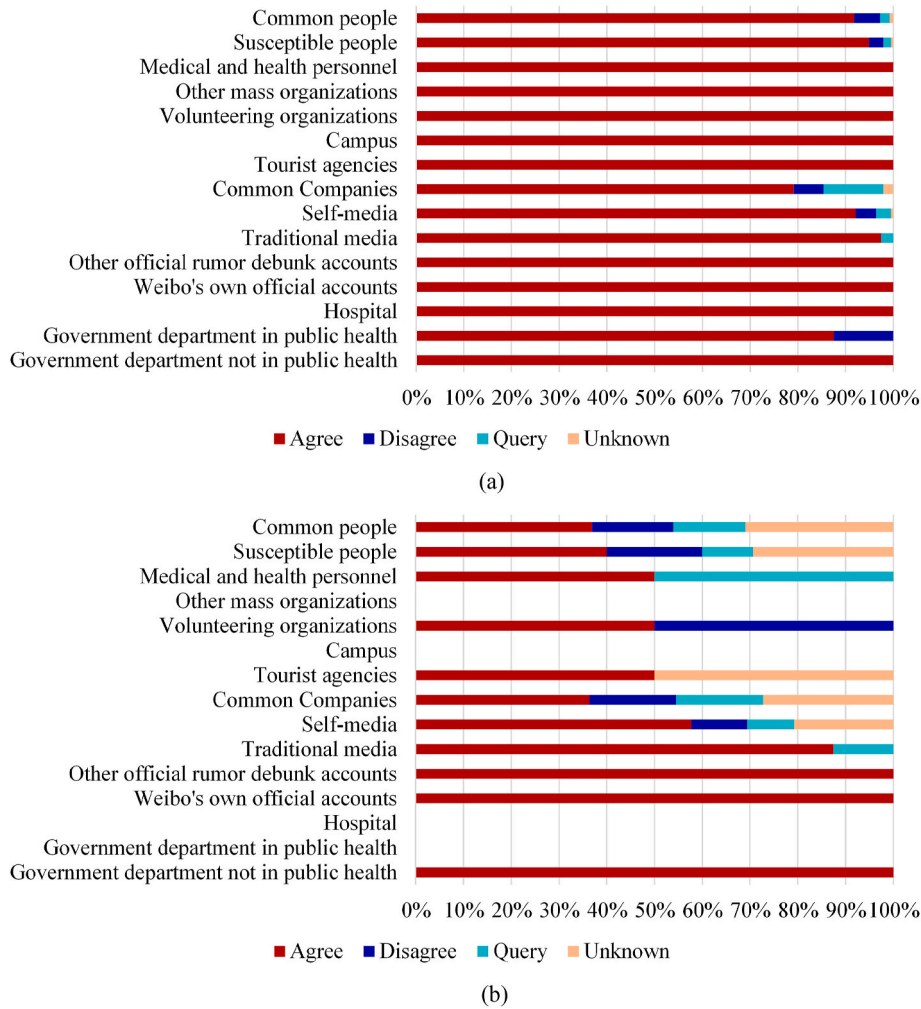


Fig. 4. Distribution of the standpoints of users with different identities in retweeting(a) and commenting(b).

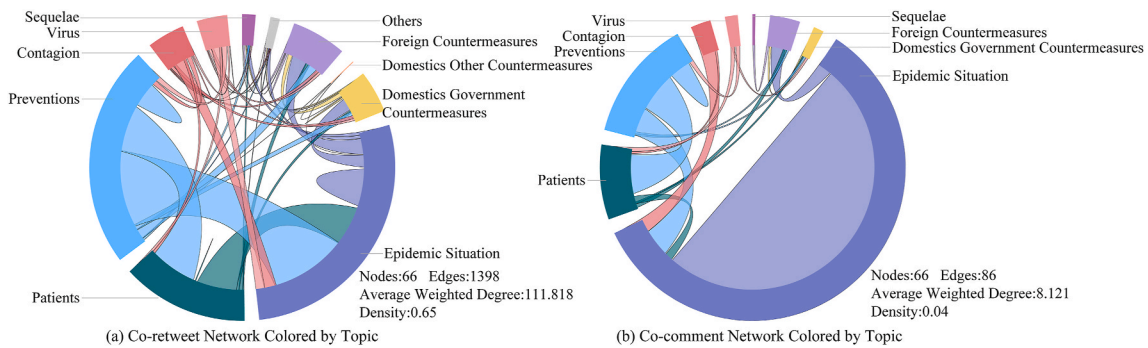


Fig. 5. Chord diagram representation of co-retweet network(a) and co-comment network(b) colored by topic.

4.3. Network structure and echo chamber effect in user networks

Compared with the retweet user network, the comment user network was smaller but denser. It contained 2381 nodes and 2591 edges (density = 0.00046, average weighted degree = 1.289), while the retweet user network contained 6743 nodes and 6818 edges (density = 0.00015, average weighted degree = 1.011). The comment user network had high clustering coefficient, transitivity and reciprocity (when the first individual chooses the second individual, the second individual also chooses the first individual), which showed that it was a cohesive community (Kartun-Giles & Bianconi, 2019), where users were closely connected

and relatively stable (Weng et al., 2013). While retweeting mostly meant one-way flow of information, and the low average path length also proved its higher information dissemination efficiency (Davidsen et al., 2002).

4.3.1. Echo chamber effect performance from identity dimension

In Fig. 9, the node size was proportional to its weighted in-degree, the thickness of the line was proportional to the weight of the edge and the line's color was consistent with the target node. It showed that in the retweet user network, traditional media, self-media, government departments not in public health, and official Weibo accounts occupied

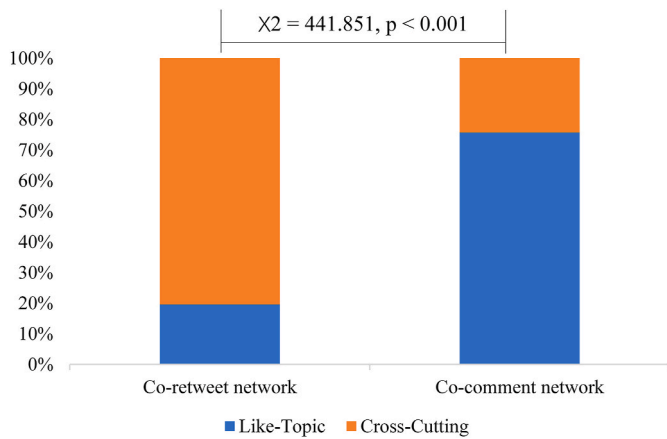


Fig. 6. Homophily measurement based on the topic of original tweets in co-retweet and co-comment network.

Table 5

Exponential random graph model results: homophily effects for the node with similar attributes in co-retweet network and co-comment network.

| Model Terms | Co-retweet network Estimate (p value) | Co-comment network Estimate (p value) |
|-------------------------------------|---------------------------------------|---------------------------------------|
| Edges | 0.683 (<1e-04 ***) | -3.797 (<1e-04 ***) |
| nodematch.topic | -0.781 (<1e-04 ***) | 1.481 (<1e-04 ***) |
| nodematch.type(refute_with_truth) | 0.264 (0.009 **) | 0.004 (0.986) |
| nodematch.type (refute_with_doubts) | -0.185 (0.597) | -1.047 (0.313) |
| nodematch.type (refute_with_rumors) | 11.883 (0.971) | -Inf (<1e-04 ***) |
| AIC | 2706 | 687.7 |
| BIC | 2734 | 710.4 |
| Null Deviance | 2974 (df = 2145) | 2973.6 (df = 2145) |
| Residual Deviance | 2696 (df = 2140) | 679.7 (df = 2140) |

Note. *p < 0.05.**p < 0.01.***p < 0.001. “-Inf(<1e-04 ***)” meant that there were no edges between nodes with the attribute of “refute_with_rumors”.

the central position. In addition to transmitting information from and to the users with the same identity as themselves, traditional media and self-media mainly retweeted information from the government. Other types of users, such as the susceptible and general public, all retweeted tweets from above opinion leaders (Hosseini Bamakan et al., 2018). In the comment user network, besides the above four, common companies and people also occupied the central place. The visualization of retweeting and commenting based on users’ identities did not show noticeable echo chamber effect, which could also be verified again in

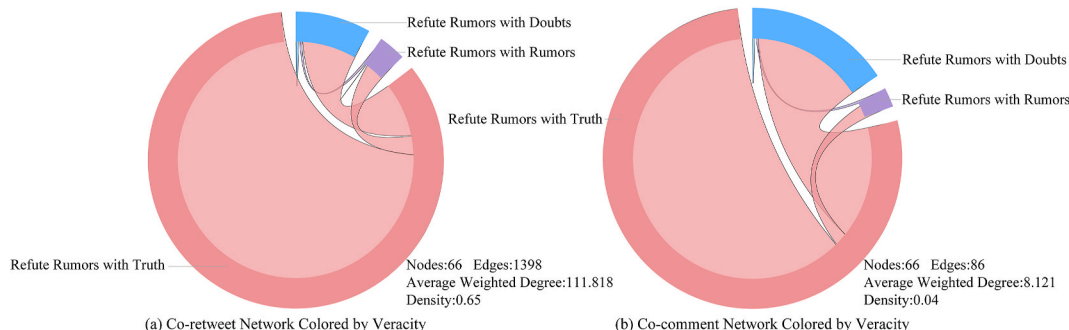


Fig. 7. Chord diagram representation of co-retweet network(a) and co-comment network(b) colored by veracity.

Table 6 (retweet: coefficient = -3.280, p < 0.001; comment: coefficient = -2.847, p < 0.001) and Fig. 10 (the number of connections between individuals with the same identity only accounted for a small proportion whether in retweet or comment user network). Although the chi-square test results claimed that the proportion of like-identity connections among users in comment user network was significantly higher than which in retweet user network.

4.3.2. Echo chamber effect performance from standpoint dimension

As Fig. 11 showed, retweet user network showed a highly modular structure, with multiple highly homogeneous large clusters isolated from each other. In contrast, in comment user network, users with opposite standpoints showed higher degree of hybridity. In Fig. 12, 90.65% (n = 6182) of the retweeting interactions shared the same standpoint, while only 37.58% (n = 1153) of the commenting interactions shared the same standpoint. More notably, the chi-square test results claimed that the proportion of like-standpoint connections among users in comment user network was significantly lower than which in retweet user network. In Table 6, we can find that users who disagreed with the rumor rebuttal or didn’t have a clear standpoint actively commented on users with different views from themselves (nodematch.disagree: coefficient = -0.671, p < 0.001; nodematch.unknown: coefficient = -0.529, p < 0.001), which further revealed the importance of comment mechanism for information seeking and gathering group wisdom. These structural patterns and quantitative indicators revealed the significance of the standpoint-based echo chamber in the retweet user network and the lower degree of homophily in the comment user network.

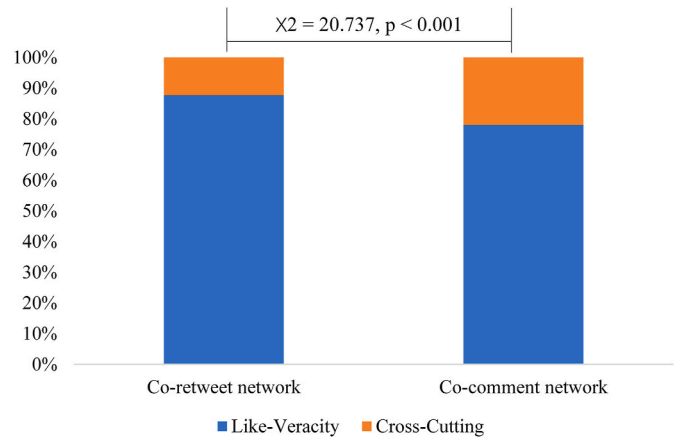


Fig. 8. Homophily measurement based on the veracity of original tweets in co-retweet and co-comment network.

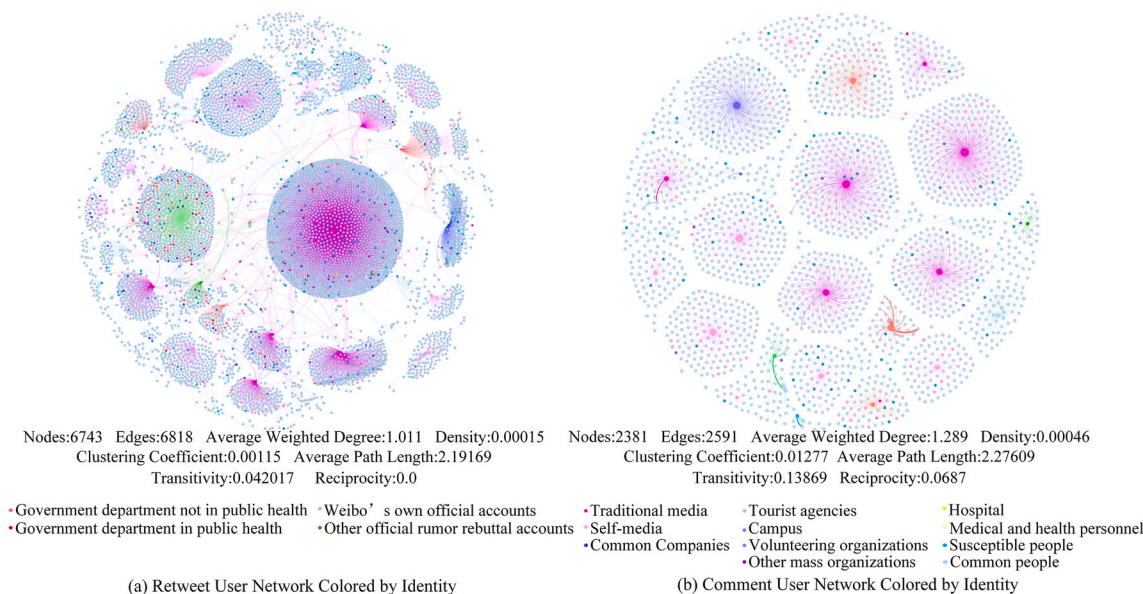


Fig. 9. Retweet user network(a) and comment user network(b) colored by users' identities visualized by Fruchterman Reingold layout algorithm in Gephi.

Table 6

Exponential random graph model results: homophily effects for the node with similar attributes in retweet user network and comment user network.

| Model Terms | Retweet user network Estimate (p value) | Comment user network Estimate (p value) |
|--------------------|---|---|
| Edges | -7.889 (<1e-04 ***) | -6.346 (<1e-04 ***) |
| nodematch.identity | -3.280 (<1e-04 ***) | -2.847 (<1e-04 ***) |
| nodematch.agree | 0.437 (<1e-04 ***) | 0.780 (<1e-04 ***) |
| nodematch.disagree | 2.366(<1e-04 ***) | -0.671(0.0004 ***) |
| nodematch.query | 2.568(<1e-04 ***) | 0.617(<1e-04 ***) |
| nodematch.unknown | 2.922 (<1e-04 ***) | -0.529(<1e-04 ***) |
| AIC | 120,116 | 39,844 |
| BIC | 120,209 | 39,925 |
| Null Deviance | 63,022,752 (df = 45,461,306) | 7,859,126 (df = 5,669,161) |
| Residual Deviance | 120,104 (df = 45,461,300) | 39,832 (df = 5,669,155) |

Note. *p < 0.05. **p < 0.01. ***p < 0.001.

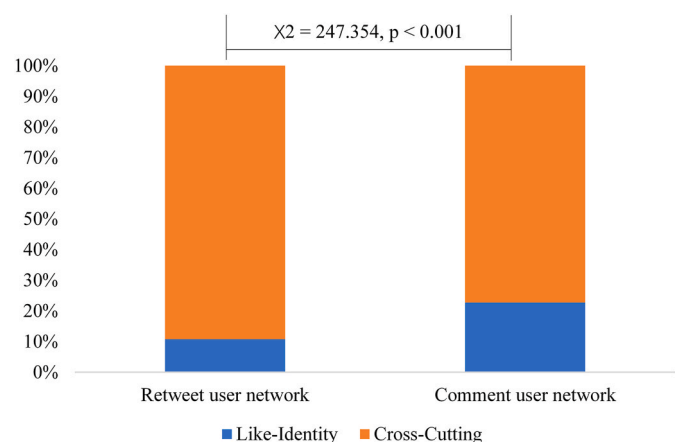


Fig. 10. Homophily measurement in retweet user network and comment user network based on the users' identities.

5. Discussion

Considering the importance of disseminating rumor rebuttal information for rumor management on social media during public health emergencies, this research took the early period of COVID-19 epidemic as an example. At that time, information was relatively vague, rumors were rampant, and rumor rebuttals spread widely. Distinct from previous intra- and inter-group communication researches which relied on self-reported perceptual or attitudinal data, this research combined content analysis, social network and statistical analysis to quantify and compare the echo chamber effect in users' retweeting and commenting on rumor rebuttals. This interdisciplinary hybrid method allowed pattern recognition and extraction for information selection according to topic and veracity, intra- and inter-group interactions based on identity and standpoint of stakeholders, by observing naturally occurring behavior data, thus enhancing the results' reliability.

5.1. The echo chamber effect in the diffuse of rumor rebuttal with different topics and veracity

Users did show significant echo chamber effect when retweeting or commenting on rumor rebuttal information with different veracity, mainly for "refute rumors with truth". However, high homophily only appeared in users' commenting on, not in retweeting, specific topics.

On the one hand, users had relatively fixed patterns when retweeting different topics, which showed a certain tendency and diversity for various information needs. Simultaneously, their commenting on different topics, especially the information related to epidemic situation, were particularly targeted.

On the other hand, users tended to only retweet or comment on information with low ambiguity and high authenticity, and ignore other contradictory content. But users who retweeted or commented on misleading information ("refute rumors with rumors", "refute rumor with doubts") did not fall into their own echo chamber, they also retweeted or commented on true information. It was obviously beneficial for rumor rebuttals that homophily significantly functioned in users' retweeting or commenting on the true information rather than the false one. Once the condition was reversed, then the echo chamber effect could be harmful, what should be concerned about was that compared with retweeting, users were more active in commenting on false or uncertain rumor rebuttals. Through this, they shared evidence in collective debates, which was conducive to exposing the

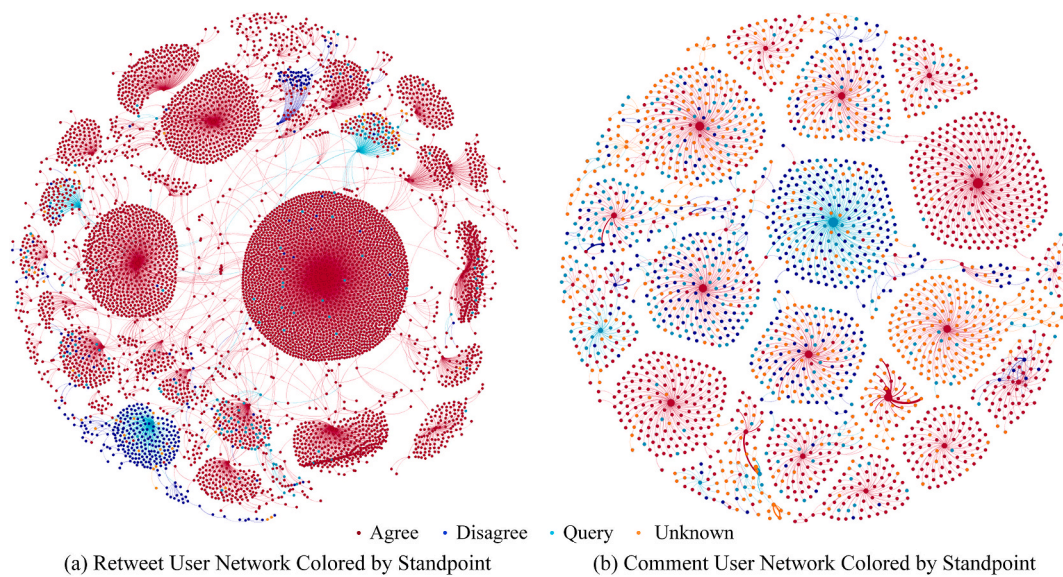


Fig. 11. Retweet user network(a) and comment user network(b) colored by users' standpoints visualized by Fruchterman Reingold layout algorithm in Gephi.

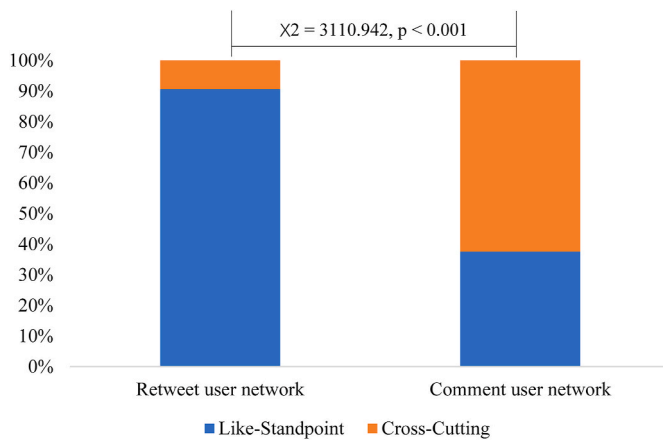


Fig. 12. Homophily measurement in retweet user network and comment user network based on the users' standpoints.

improper behaviors such as “refute rumors with rumors” (Katz & Shibutani, 1969).

5.2. The echo chamber effect in user intra and inter group communication

The echo chamber effect based on identities of stakeholders was not significant in both retweet and comment user networks. Weibo's direct and open channels broke the boundaries between users from different professional fields, which was consistent with the research of Zhang and Ho (2020). In retweet user network, media, government and Weibo platform's own accounts served as the information centers. Traditional media and self-media mainly retweeted information from peers and the government, which might be attributed to political aspects. Traditional media have a government license, meaning that these online news providers should obey all the official information publication protocols, as a notice was issued in 2013 to prohibit journalists from reporting stories based on unverified online sources (Guo, 2020). In comment user network, apart from the above three influential roles, some common companies and people also locate at the network's center, meaning that compared with retweeting, commenting mechanism had set up a looser psychological threshold for users to communicate (Liu et al., 2017).

Standpoint-based echo chamber significantly existed in retweet user

network. Interactions between users holding different standpoints were limited. Although previous studies showed that social media could increase access to anti-attitude messages and reduce polarization (Beam et al., 2018), our findings emphasized the universality of self-isolation, which indicated a more proactive engagement level than information consumption through retweeting (Tsai & Men, 2018). Boyd et al. (2010) pointed out that, affected by individual or community factors (like value identity, group pressure), spiral of silence and confirmation bias might appear when users retweeted controversial divergent issues. Individuals intentionally avoided expressing dissent, or tended to stay close to others who might support their own opinions, to do self-confirm in the homophily network. Therefore, large-scale interactive retweeting might reflect the nature of collective activism around rumor rebuttal, and combined with the explanation above that the low homophily based on professional fields might promote information sharing among different stakeholder groups, it should be noticed that retweeting mechanism had significant advantages in launching large-scale mobilization.

Unlike retweeting, standpoint-based echo chamber effect did not significantly exist in comment user network, which was consistent with the researches of Tsai et al. (2020), Wang and Song (2020). Commenting mechanism was conducive to sharing knowledge, condensing group wisdom, promoting mutual understanding and integration among groups with opposing views. Spiral of silence (Noelle-Neumann, 1974) did not seem to work. On the one hand, it might be attributed to the fact that the comment mechanism reduced the individuals' exposure ratio in social networks compared with retweeting (Liu et al., 2017). On the other hand, it might be due to the different purposes when users used different interaction mechanisms, which was when users responded to something they disagreed with, they would choose to comment on rather than retweet it, avoiding amplifying its visibility (Tsai et al., 2020).

5.3. Theoretical contributions

The theoretical contributions were as follows: firstly, previous researches on echo chamber effect paid more attention to rumors, and few studies explored the form and degree of echo chamber effect during the dissemination of rumor rebuttals. This research made up for this gap.

Secondly, this research used social network analysis method, focusing on the explicit connections among users (communication flow networks) and implicit connections among information (representative networks). Based on the analysis of different-type networks, we could

get diverse conclusions about echo chamber effect, and expand the application mode and field of social network theory.

Thirdly, this research compared the similarities and differences of echo chamber effect in users' retweeting and commenting behaviors, which broadened the researches on the influence of social media functions on user behaviors.

Last but not the least, this research explored the form of echo chamber effect from multiple dimensions (the information' topics and veracity in representative networks, the users' identities and standpoints in communication flow networks), comprehensively verifying and enriching the literatures related to echo chamber.

5.4. Practical implications

The findings could provide strategic guidance for rumor governance departments to guide the communication and collaboration among stakeholders, to eliminate rumors more efficiently during public health emergencies.

Firstly, the government should quickly release multi-topic and comprehensive information about the epidemic as soon as it broke out, aiming to avoid information vacuum, prevent cognitive defects and narrow bias. Personalized information recommendation services can be appropriately used to push user-focused frequent topic combinations.

Secondly, the misleading information which refutes rumors with rumors has some concealment that users may lack judgment on its veracity before retweeting. The rumor governance departments should strengthen the monitoring of such messages.

Thirdly, managers should monitor the distribution of stakeholders' opinions in retweeting and commenting networks in real-time, and adopt differentiated strategies to guide public opinion. Misleading messages that interfere with rumor-rebuttals in retweeting network are masked due to echo chamber effect, but exposed in commenting network. For retweeting, we should guard against illegal behaviors that incite anti-rumor-rebuttal sentiment and create large-scale collective panic. For commenting, we should consider how to better use it as an ideal platform for multilateral exchanges of organizations, resolving conflicts of interest, and promoting the integration of views.

Fourthly, we did not find any patients who did self-statement getting ill in retweeting or commenting. This may result from stigmatization discrimination exacerbated by an echo chamber. Public opinion propaganda should guide people to establish comprehensive, objective views for the disease.

Finally, the government, Weibo platform, and traditional media do play an essential role in rumor rebuttal. However, some government public health departments and traditional media also inadvertently release statements contrary to rumor rebuttals. Meanwhile, public frequently comment on the government, showing their strict supervision. The establishment of official authority has a long way to go.

5.5. Limitation and future research directions

The mentioning ("@" mechanism on Weibo can also be used to exchange information with specific audiences. The echo chamber effect may differ in the non-targeted exposure through retweeting/commenting and the targeted request through mentioning. Future researches should make the differentiation. Besides, longitudinal researches on the dissemination of rumor rebuttals can shed light on the dynamic changes in the formation and resolution of echo chamber in online communities. Such researches may ask whether cross-domain interactions have reached consensus over time or are subdivided due to ideological differences. Life cycle theory or statistical analysis methods combined with time series can be used for in-depth exploration.

6. Conclusion

This research systematically explored the form and degree of echo

chamber effect in users' retweeting and commenting behaviors on Weibo's discussion about rumor rebuttals related to COVID-19 during the early stage of the epidemic. It was confirmed that there was a significant veracity-based but insignificant identity-based echo chamber effect in users' retweeting and commenting behaviors. Significant topic-based echo chamber effect existed in users' commenting behavior and standpoint-based echo chamber effect existed in users' retweeting behavior. Like-minded and cross-standpoint communication coexisted in users' commenting behavior. The findings provided meaningful inspiration for public opinion managers to use or eliminate the echo chamber to improve the rumor rebuttal strategies' effectiveness.

Credit author statement

Dandan Wang: Conceptualization; Methodology; Software; Formal analysis; Data curation; Visualization; Writing – original draft; Writing – review & editing. **Yadong Zhou:** Software; Data curation; Visualization. **Yuxing Qian:** Writing – review & editing. **Yunmei Liu:** Writing – review & editing.

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