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Research on the Influence of Individual Psychological Effects on Rumor Spreading and Controlling of Public Emergencies

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Keywords

Individual psychological effect
Public emergencies
Rumor dissemination

Abstract.

Exploring rumor dissemination model of public emergencies and its prevention and control strategies under the individual psychological effects has great theoretical and practical significance. Considering the individual psychological effects in the process of rumor spreading, a nonlinear spreading strength function is defined, and a rumor dissemination model affected by psychological effects is constructed, then verifying its effective application through stability analysis and numerical simulation. Results show that the spread of rumors presents different evolutionary trends based on different threshold characteristics, adjusting the parameters can make the rumors gradually disappear; the spread rate of rumors significantly affects the final quantitative changes of various groups of people; individual psychological effects affect the trend of the spreading strength of rumors, thereby changing the disseminator quantity.

1. Introduction

Sudden crisis events such as earthquakes, nuclear leaks, and infectious disease epidemics seriously threaten people’s property and lives, and often burst out massive amounts of information closely related to the public, rumors are always accompanied by them. Compared with general information, rumors have a higher degree of freshness, and their spread is faster, farther and deeper (Vosoughi et al., 2018). Under the complex background of the international political and economic situation, the public is prone to fear, anxiety and other emotions and psychology in sudden crisis events, and they often cannot think and respond with common sense (Hang & Wu, 2020; Huo & Huang, 2011). For example, in the early stages of the spread of rumors that “radix isatidis can prevent COVID-19”and the nuclear leak of Fukushima nuclear power plant in Japan caused “iodized salt against cancer”, people were blindly demanded for information with fear and anxiety, which had a great negative impact on society. Therefore, considering the psychological changes of the spread subject in emergencies, studying how individual psychological effect affects the diffusion of rumors and their intervention has important theoretical and guiding significance.

For a long time, sudden public incidents have often caused great worry and fear to the public, and have provided a specific environment for the breeding and spread of rumors. Scholars' discussion on the spread of rumors first started with the model of infectious disease dynamics. A classic SIR rumor dissemination model is proposed by dividing the information audience into S (uninformed), I (disseminators) and R (immunizers) (Daley & Kendall, 1965). Later, researchers continued to develop and enrich the classical model, analyzed the diversity characteristics of scale-free network structure and established a rumor spread dynamic model based on the infectious disease model (Hosseini et al., 2015). Enatsu et al. (2012) built a SIRS transmission model that includes re-infection in response to situations in which immunized people may be re-infected. Zhang and Xia (2021) introduced the "long tail" spreading phenomenon of rumors into the SIRS model, and constructed a rumor spreading model based on the dynamic game of incomplete information. Chen et al. (2011) considered the time lag and periodicity in the diffusion process of public information, and proposed a SEIR spreading model including latent nodes. Zhu and Ma (2019) supplemented the hesitated crowd in the process of rumor dissemination, and constructed a rumor dissemination model based on SHIR. Xiao et al. (2019) proposed a SKIR dynamic model based on the evolutionary game theory for the known mechanism of anti-rumor spreading in the process of rumor spreading. Zhang et al. (2020) combined the emotional infection theory with the infectious disease model, and built an IESR model of group emotional transmission based on the cumulative effect of negative emotions. Wang and Hou (2019) considered the new roles of spectators and rumors in the process of rumor spreading, and established an improved WT-SIR rumor dissemination model. From different perspectives of interpersonal relationship networks and multi-layer complex networks, Zhu et al. (2017) and Zhu et al. (2018) proposed a rumor spreading model based on multi-agent complex networks, and conducted in-depth researches on rumor diffusion and immune thresholds. Zhang et al. (2021) explored the rumor spreading through social media taking into account self-purification mechanism, and suggested paying attention to individuals' self-judgment ability to strengthen the self-purification of rumors.

These studies analyze and model from the perspective of different information participants, and have achieved relatively rich results. As the research questions shift from biomedicine to psychology, sociology, etc., the role and application of individual psychological effects in infectious disease models are getting more and more attention. Fu (2019) considered the patient's psychological effects and active treatment effects in the spread of the disease, built a differential equation based on SIS, and analyzed its stability and limit conditions. Yao and Li (2020) set the parameters of the influence of psychological effects on the intensity of infection, and discussed the overall nature of the SIRS model with psychological effects. Wang and Xue (2021) established a similar SEIRS model and found that public's psychology does not affect the stability of the equilibrium point. Ding and Luo (2015) used psychology and spreading theories to propose three stages of changes in public psychology: psychological shock period, psychological defense period, and psychological recovery period.

The current research provides a solid theoretical basis for the dissemination and intervention of rumors under sensitive issues of public concern or public emergencies especially under the normalized prevention and control of the COVID-19 epidemic, due to public psyche needs more attention than at other times. However, combing the existing theoretical and practical studies found that: (1) the analysis of rumor spread basically stems from the evolution of infectious disease models, most studies are aimed at constructing spreading models of various situations, while the psychological effects of individuals at the micro level affect the process and mechanisms of rumor dissemination are less involved; (2) a reasonable description of the non-linearity spreading law of rumors and consideration of the individual psychological effects in public emergencies requires further analysis, and an appropriate model needs to be constructed to reveal the role of individual psychological effects on rumor dissemination, so as to effectively intervene the results of rumor dissemination.

Therefore, this study introduces the individual psychological effects, and defines the function of non-linear rumor spreading in the process of rumors spreading of public emergencies, so as to construct a rumor dissemination model influenced by psychological effects on the framework of the classic D-K model which established by Daley and Kendall (1965). The rest of this paper is organized as follows. The rumor dissemination model of nonlinear spreading strength under the individual psychological effects is constructed, than the local and global stability of the model are discussed in Section 2. Section 3 performs numerical simulation and simulation analysis on the model under different parameters by using Matlab2015b, and Section 4 concludes our paper.

2. Model construction and analysis

2.1. Construction of rumor dissemination model

Rumor diffusion is very similar to the spread of infectious diseases, which are caused by "contact" between people. Ding and Luo (2015) point that the influence of individual psychological effects on the spread of rumors cannot be ignored. In the early stage of public emergencies, it is easy to cause panic and anxiety in the crowd. In this state of mind, individuals blindly demand rumors and their cognitive evaluation is to accept or deny: accepting rumors adopts a herd mentality and ignores self-judgment criteria to spread rumors; while denying rumors treats information in terms of understanding and thinking, and does not spread rumors. When individuals face stress or emergencies, some actively process information and rely on self-understanding and judgment; some react negatively and follow the trend and spread rumors. At this stage, the spread of rumors showed a non-linear growth, rapidly increasing to a peak. However, with the implementation of the government's emergency response plan and the release of expert opinions and authoritative information, individuals' psychological needs and cognitive evaluations for information have gradually recovered, and the motivation for the spreading of rumors has diminished. In the process of rumors dissemination and clarification, the spreading intensity between individuals is affected by psychological effects, and its changing trend is manifested as a dynamic process from low to high and then decreasing, which depends on the base of rumors disseminators.

In this regard, our study draws on Tang et al. (2008) and Yao and Li (2020) to improve the bilinear incidence rate of the infectious disease model, a nonlinear function $g(I)$ is defined to describe the trend of rumor propagation dynamics based on the disseminators (I) under the psychological effects. Aiming at the issue of rumors dissemination in an open virtual community, here we draw on the classic D-K model and consider three types of people, namely, uninformed individuals, disseminators and immunizers. To simplify the model, the hypothesis parameters of rumors dissemination are proposed below Table 1.

Table 1: Relevant hypothetical parameters and their meanings and explanations.

Parameters	Meanings and explanations
S	Uninformed individuals, who do not know the rumors.
I	Disseminators, who believe and spread the rumors.
R	Immunizers, who know the rumors but do not believe them through identification or lose their interest in spreading rumors.
λ	The entry rate of people into an open virtual community.
μ	The exit rate of three groups in the open virtual community.
β	Immunization rate: the probability of a rumor disseminator is clarified when encountering immunizers, or encounters other disseminators losing the motivation to spread rumors.
γ	Propagation rate: the probability of an uninformed person spreading rumors after "touching" disseminators.
α	The degree of attention or influence of the event.
η	The psychological needs for information or the degree of interest in rumors.

As analyzed above, the nonlinear function $g(I)$ is affected by the individual's psychological needs for information or the degree of interest in rumors, and the degree of attention to related event or its own influence. Combined with the assumed parameters in Table 1, the specific expression is defined as $g(I) = \eta I/(1 + \alpha I^2)$. The dynamic spreading process of rumors in the virtual community is shown in Figure 1.

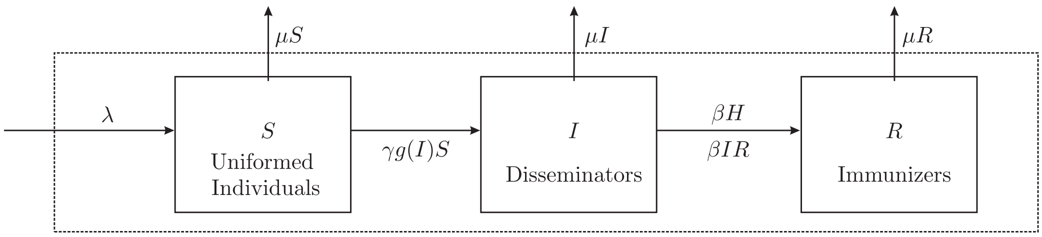


Figure 1: The dynamic model of rumors spreading under the individual psychological effects.

According to the parameter settings in Figure 1 and above, based on the classic D-K model framework constructed by Daley and Kendall (1965), adding the influence of individual psychology on the spread of rumors that has non-linear spreading strength for public emergencies, the corresponding dynamic model of the differential equation of rumor dissemination is established:

$$\begin{cases} \dfrac{dS}{dt} = \lambda - \gamma\eta IS/(1+\alpha I^2) - \mu S, \\ \dfrac{dI}{dt} = \gamma\eta IS/(1+\alpha I^2) - \beta II - \beta IR - \mu I, \\ \dfrac{dR}{dt} = \beta IR + \beta II - \mu R. \end{cases} \tag{2.1}$$

In the differential equation (2.1), the parameters $\lambda, \mu, \eta, \gamma, \alpha, \beta$ are all non-negative real variables, and the three equations describe the changing trends of the quantity of rumors uninformed, disseminators and immunizers. If the quantity does not change over time, the spread of rumors tends to stabilize.

2.2. Stability analysis of the rumor dissemination model

As the above differential equation (2.1) reaches a stable state, the quantity of the three groups of people remains unchanged, that is, the right side of the equation is equal to zero:

$$\begin{cases} \lambda - \gamma\eta IS/(1+\alpha I^2) - \mu S = 0, \\ \gamma\eta IS/(1+\alpha I^2) - \beta II - \beta IR - \mu I = 0, \\ \beta IR + \beta II - \mu R = 0. \end{cases} \tag{2.2}$$

When $I = 0$, (2.2) has a unique non-negative equilibrium solution $D_0(\lambda/\mu, 0, 0)$; when $I \neq 0$, the elimination method substitutes the upper and lower formulas in (2.2) into the middle formula, simplification can be obtained:

$$\alpha\mu^3 + \gamma\eta(\lambda\beta + \mu^2)I + \mu^3 - \lambda\mu\gamma\eta = 0,$$

Known:

$$\begin{aligned} \Delta =& \gamma^2\eta^2\left(\lambda\beta + \mu^2\right)^2 - 4\alpha\mu^3(\mu^3 - \lambda\mu\gamma\eta), \\ =& \gamma^2\eta^2\left(\lambda\beta + \mu^2\right)^2 + 4\alpha\mu^6(R_0 - 1), \end{aligned}$$

where $R_0 = \lambda\gamma\eta/\mu^2$.

If $R_0 < 1$, then $-\gamma\eta(\lambda\beta + \mu^2) + \sqrt{\Delta} < 0$; if $R_0 \geq 1$, then $-\gamma\eta(\lambda\beta + \mu^2) + \sqrt{\Delta} \geq 0$. Therefore, if $R_0 = \lambda\gamma\eta/\mu^2 < 1$, equation (2.2) has no non-negative equilibrium solution; if $R_0 = \lambda\gamma\eta/\mu^2 \geq 1$, equation (2.2) has a specific non-negative equilibrium solution D_1. Among them, when $R_0 = \lambda\gamma\eta/\mu^2 = 1$, $\Delta = \gamma^2\eta^2\left(\lambda\beta + \mu^2\right)^2$, then $I^* = 0$, at this time the non-negative equilibrium solution is $D_0(\lambda/\mu, 0, 0)$.

Where $D_1(S^*, I^*, R^*) = D_1\left(\dfrac{\lambda(\mu - \beta I^*) - \mu^2 I^*}{\mu(\mu - \beta I^*)}, \dfrac{\sqrt{\Delta} - \gamma\eta(\lambda\beta + \mu^2)}{2\alpha\mu^3}, \dfrac{\beta I^{*2}}{\mu - \beta I^*}\right)$.

Theorem. *When $R_0 = \lambda\gamma\eta/\mu^2 \leq 1$ is satisfied, the rumor dissemination in the virtual community is ultimately only for the uninformed, the disseminators and immunizers are* *approaching "vanish"; when* $R_0 = \lambda\gamma\eta/\mu^2 > 1$, *rumor uninformed, disseminators, and immunizers coexist in the virtual community in a certain number* $D_1(S^*, I^*, R^*)$.

Proof. If the quantity of the three groups are taken as the initial values of $S(t_0)=S_0$ $I(t_0)=I_0$ $R(t_0)=R_0$, the total quantity in the community is $N_0=S_0+I_0+R_0$. If $t\to\infty$, then $\lambda/\mu=S(t)+I(t)+R(t)$. Substitute (2.2) to get its isomorphic formula (2.3):

$$\begin{cases} \dfrac{dS}{dt} = \lambda - \gamma\eta IS/(1+\alpha I^2) - \mu S = U(S,I), \\ \dfrac{dI}{dt} = \gamma\eta IS/(1+\alpha I^2) - \beta I(\lambda/\mu - S) - \mu I = V(S,I). \end{cases} \tag{2.3}$$

(2.2) and (2.3) belongs to a system of isomorphic equations and have the same properties. Reference to Perko [10], taking the Dulac function $P = (1+\alpha I^2)/\gamma\eta I$, the trajectory property of (2.3) is analyzed. Since $S < \lambda/\mu$, there is

$$D(U,V) = \frac{\partial(PU)}{\partial S} + \frac{\partial(PV)}{\partial I} = \frac{\mu^2 + \mu\gamma\eta I + 3\alpha\mu^2 I^2 + 2\alpha\beta(\lambda-\mu S)I^2}{\mu\gamma\eta I} < 0.$$

According to the Dulac criterion, if $D(U,V) < 0$, so that (2.3) has no limit cycle in real number set. Therefore, (2.3) has no closed orbit.

For the dynamic analysis of the non-negative equilibrium points $D_0(\lambda/\mu, 0, 0)$ and $D_1(S^*, I^*, R^*)$, let $s = \lambda/\mu - S$, $i = I$, $\tau = \mu t$, formula (2.3) is transformed into formula (2.4), there is

$$\begin{cases} \dfrac{ds}{d\tau} = -\dfrac{\gamma\eta i}{\mu^2(1+\alpha i^2)}(\lambda - \mu s) - s, \\ \dfrac{di}{d\tau} = \dfrac{\gamma\eta i}{\mu^2(1+\alpha i^2)}(\lambda - \mu s) - \frac{\beta}{\mu} si - i. \end{cases} \tag{2.4}$$

It can be seen that formula (2.4) has equilibrium solutions $D_0'(0,0)$ and $D_1'(s^*, i^*)$, where $s^* = \dfrac{\mu i^*}{(\mu - \beta i^*)}$, $i^* = \dfrac{-\gamma\eta(\lambda\beta + \mu^2) + \sqrt{\Delta'}}{2\alpha\mu^3}$, $\Delta' = \Delta$.

For the zero balance point $D_0'(0,0)$, its Jacobian Matrix is

$$J_0' = \begin{pmatrix} -1 & -\lambda\gamma\eta/\mu^2 \\ 0 & (\lambda\gamma\eta - \mu^2)/\mu^2 \end{pmatrix} = \begin{pmatrix} -1 & -R_0 \\ 0 & R_0 - 1 \end{pmatrix}$$

If $R_0 < 1$, the eigenvalues of J_0' are all negative, then $D_0'(0,0)$ is the stable point; the same if $R_0 > 1$, $D_0'(0,0)$, is the unstable point; if $R_0 = 1$, the formula (2.4) is in the neighborhood of $D_0'(0,0)$

$$\begin{cases} \dfrac{dS}{d\tau} = i - \gamma\eta si/\mu - \mu + O\big((s,i)^3\big), \\ \dfrac{di}{d\tau} = -(\gamma\eta + \beta)si/\mu + O\big((s,i)^3\big). \end{cases}$$

According to the non-hyperbolic critical point theorem of plane analysis system in Perko (1996) on page 150, $D_0'(0,0)$ is a saddle point.

For non-zero equilibrium point $D_1'(s^*, i^*)$, its Jacobian matrix is

$$J_1' = \begin{pmatrix} -1 - \dfrac{\gamma\eta i^*}{\mu(1+\alpha i^{*2})} & -\dfrac{\alpha\gamma\eta(\lambda-\mu s^*)i^{*2}}{\mu\big(1+\alpha i^{*2}\big)^2} + \dfrac{\gamma\eta(\lambda-\mu s^*)}{\mu^2(1+\alpha i^{*2})} \\ -\dfrac{\gamma\eta i^*}{\mu(1+\alpha i^{*2})} - \dfrac{\beta}{\mu} i^* & -\dfrac{\mu+\beta s^*}{\mu} - \dfrac{2\alpha\gamma\eta(\lambda-\mu s^*)y^{*2}}{\mu^2\big(1+\alpha i^{*2}\big)^2} + \dfrac{\gamma\eta(\lambda-\mu s^*)}{\mu^2(1+\alpha i^{*2})} \end{pmatrix}.$$

Then the determinant of matrix J_1'

$$\begin{aligned} Det(J_1') &= \frac{\gamma\eta(\lambda-\mu s^*)}{\mu^2(1+\alpha i^{*2})}\left(1+\frac{\gamma\eta i^*}{\mu^2(1+\alpha i^{*2})}\right) - \frac{\mu+\beta s^*}{\mu}\left(-\frac{2\alpha\eta(\lambda-\mu s^*)i^{*2}}{\mu^2(1+\alpha i^{*2})} + \frac{\gamma\eta(\lambda-\mu s^*)}{\mu^2(1+\alpha i^{*2})}\right) \\ &= \frac{\gamma\eta i^*(\lambda-\mu s^*)S}{\mu^4(1+\alpha i^{*2})s^*}, \end{aligned}$$

where $S = \gamma\eta\lambda + \mu^2(\alpha i^{*2} - 1)$.

Substituting $i^* = \dfrac{-\gamma\eta(\lambda\beta+\mu^2)+\sqrt{\Delta'}}{2\alpha\mu^3}$ into the above formula can be simplified to have:

$$\begin{aligned} S &= \lambda\gamma\eta + \left(\frac{\alpha\big(-\gamma\eta(\lambda\beta+\mu^2)+\sqrt{\Delta'}\big)^2}{4\alpha^2\mu^6} - 1\right)\mu^2 \\ &= \frac{2\sqrt{\Delta'}\big(-\gamma\eta(\lambda\beta+\mu)^2+\sqrt{\Delta'}\big)}{4\alpha\mu^4}. \end{aligned}$$

If $R_0 > 1$, $\sqrt{\Delta'} - \gamma\eta(\lambda\beta+\mu)^2 < 0$, then $S < 0$. And $s^* < \lambda/\mu$, then $Det(J_1') < 0$, so, the trace of matrix J_1':

$$Tr(J_1' = -\left(1 + \frac{\gamma\eta\imath^*}{(\mu+\alpha\mu i^{*2})}\right) - \frac{2\alpha\gamma\eta(\lambda-\mu s^*)i^{*2}}{\big(\mu+\alpha\mu i^{*2}\big)^2} > 0.$$

According to the Routh-Hurwitz theory in Rao (1969), the root of characteristic equation of the system is the pole of the system, and the sufficient and necessary condition for the stability of the system is that all roots of its characteristic equation are negative numbers or have negative real number parts. It can be judged that the non-zero equilibrium point $D_1'(s^*, i^*)$ is the locally asymptotically stable point of formula (2.4). Since formula (II) has no closed orbits in the feasible region and is topologically homeomorphic to formula (2.4), so the only locally asymptotically stable point is the global asymptotically stable point. Similarly, when $R_0 \le 1$, the non-negative equilibrium solution $D_1'(s^*, i^*)$ is an unstable point.

Based on the above analysis and the homogeneity of formulas (2.2), (2.3) and (2.4), when $R_0 = \lambda\gamma\eta/\mu^2 \le 1$, $D_0(\lambda/\mu, 0, 0)$ is the global asymptotic stability point of (2.2); when $R_0 = \lambda\gamma\eta/\mu^2 > 1$, $D_1(S^*, I^*, R^*)$ is the global asymptotic stability point of (2.2), and $D_0(\lambda/\mu, 0, 0)$ is the unstable point. That is, when $R_0 = \lambda\gamma\eta/\mu^2 \le 1$, there are only rumor uninformed individuals in the community, disseminators and immunizers approaching "vanish"; when $R_0 = \lambda\gamma\eta/\mu^2 > 1$, rumor uninformed individuals, disseminators and immunities tend to stabilize in a certain number. The certificate is complete.

As the theorem analysis in this paper, there is a threshold $R_0 = \lambda\gamma\eta/\mu^2$ for the spread of rumors of public emergencies under the influence of individual psychological effects. It can be found that the threshold R_0 is directly related to the population entry rate, exit rate, rumors spreading rate and psychological effects, and the relationship between R_0 and 1 influence the results of rumors spreading in virtual communities. In particular, when $R_0 < 1$, relevant departments can adjust the final evolution of various groups of individuals by changing the parameter values in R_0, and intervene in the spread of rumors.

3. Numerical Simulation and Simulation Analysis of the Model

In order to verify the effectiveness of the above model, Matlab2015b is used to numerically simulate the rumor dissemination model with nonlinear spreading strength under the individual psychological effects. Suppose that a large number of rumors disseminators are generated in an open community after a public emergency occurs, and the initial quantity is $S_0 = 0$, $I_0 = 4$ (ten thousand), $R_0 = 0$ (the unit of the vertical axis in the figure below are all ten thousand). As mentioned above, there is a critical threshold R_0 in the rumor dissemination model constructed in this research. If $R_0 = \lambda\gamma\eta/\mu^2 \leq 1$, assuming that a large number of uninformed persons emerge in the community and the spread of rumors remains a low spreading intensity and infection rate, take the parameters $\lambda = 0.8$, $\mu = 0.15$, $\eta = 0.1$, $\gamma = 0.1$, $\alpha = 0.5$ and $\beta = 0.2$ refer to Wang et al. (2021) and Zhang et al. (2020). It can be found the three types of people in the community tend to stabilize point D_0, and both disseminators and immunizers have been removed or disappeared. The simulation results are shown in Figure 2(a). If $R_0 = \lambda\gamma\eta/\mu^2 > 1$, it is assumed that a large number of uninformed persons emerge in the community but the spread of rumors is maintained at a high spreading intensity and infection rate, taking the parameters $\lambda = 0.8$, $\mu = 0.25$, $\eta = 1.25$, $\gamma = 0.8$, $\alpha = 0.5$ and $\beta = 0.2$, finally the three types of people in the community tend to stabilize at D_1. The simulation results are shown in Figure 2(b).

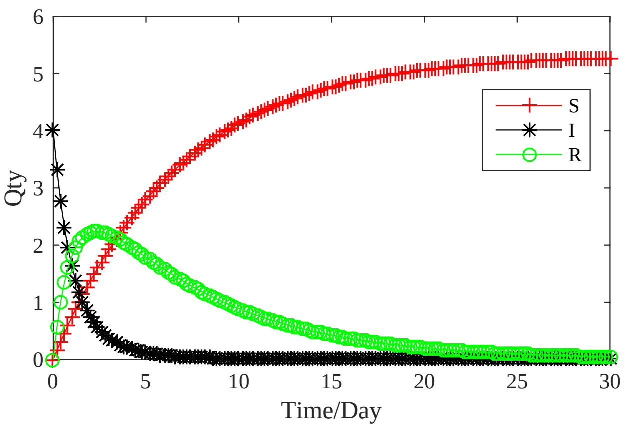


Figure 2(a). The evolution trend of the three groups when $R_0 \leq 1$.

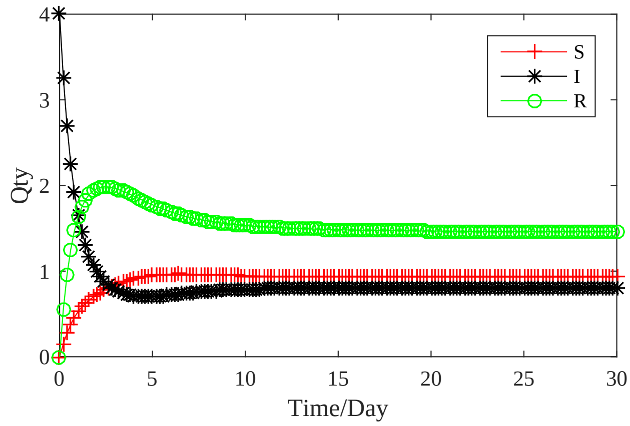
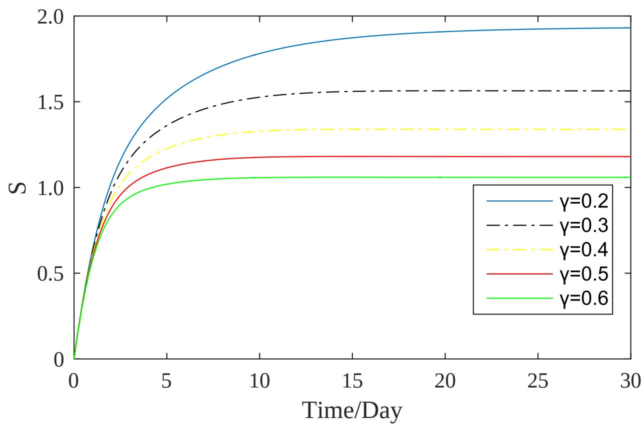


Figure 2(b). The evolution trend of the three groups when $R_0 > 1$.

The above simulation shows that when the threshold $R_0 > 1$, all three types of people exist, which necessitates to intervene and control the spread of rumors. The following is a simulation of the key parameter γ (infection rate) that affects the results of the spread of rumors. If the other parameters are fixed, taking the parameter $\gamma = 0.2$, 0.3, 0.4, 0.5 and 0.6, the change curves of the three types of people S, I and R in the community are shown in Figure 3. It shows that the larger the value of γ, the quantity of uninformed individuals and immunizers in the open community will decrease, while the quantity of disseminators will increase. This is in line with the basic laws of infectious diseases, and also shows that the final results of S, I and R can be optimized by adjusting the parameter γ, especially reducing the value of γ.



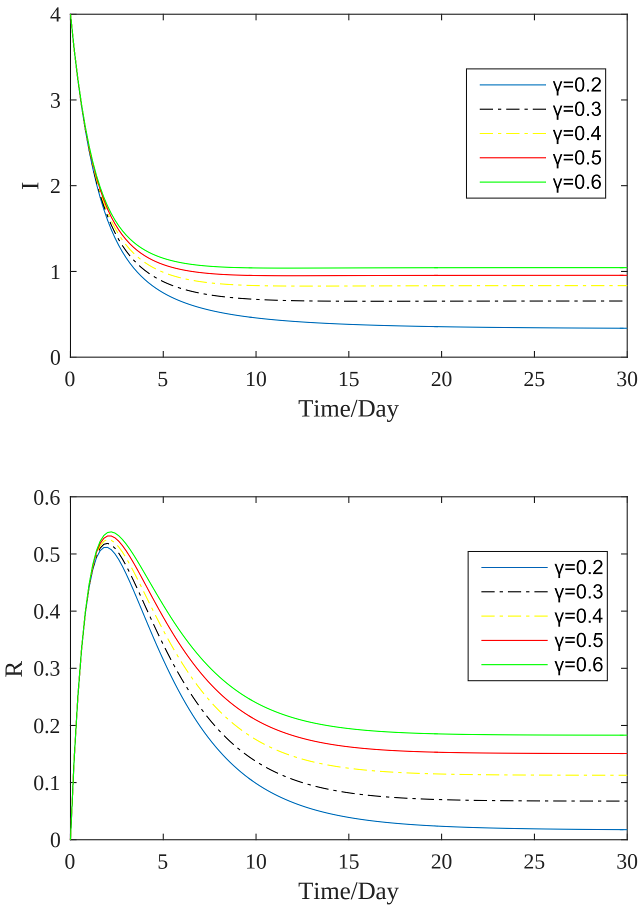


Figure 3. The influence of different values of γ on the quantity of S, I and R.

In particular, the influence of psychological effects on the non-linear spread of rumors is related to the parameters η and α. In the case of $R_0 > 1$, if other parameters are fixed and only change the value of η and α, the change trend of the quantity of disseminators in the community is shown in Figure 4. In the nonlinear spreading strength function $g(I)$, η reflects the individual's psychological needs for information or the degree of interest in rumors. The greater the individual's psychological demand for information or interest in rumors, the greater the psychological effect on the individual. Then the spread between individuals increases, and finally the quantity of rumor spreaders is higher; and vice versa. Therefore, it is necessary to take measures to control η to take a smaller value to effectively reduce the communicators.

While α reflects the degree of individual's attention to the event or the impact of event itself, and the change of its value will affect the individual psychological effects. Although it does not affect the value of R_0 and does not change the curve trend of spreading intensity first increasing and then decreasing, the numerical simulation of α shows that it still has a direct impact on the efficiency of rumor management and control. As emergency departments conduct authoritative reporting and information release or expands its influence on public emergencies, it is obvious that the impact of the event itself or the degree of individual concern about the event increase. The public's ability to evaluate and interpret rumors will be improved, so that they will be less affected by other individuals, and finally the quantity of disseminators tends to decrease. That is, when the value of α increases from small to large, the quantity of disseminators will eventually decrease. It comprehensively shows that in the process of rumor dissemination of sudden public events, regulating the value of η and α by paying attention to and guiding individual psychology, authoritative reporting of events, etc, can effectively intervene (minimize the number of disseminators) in the state of rumor spreading.

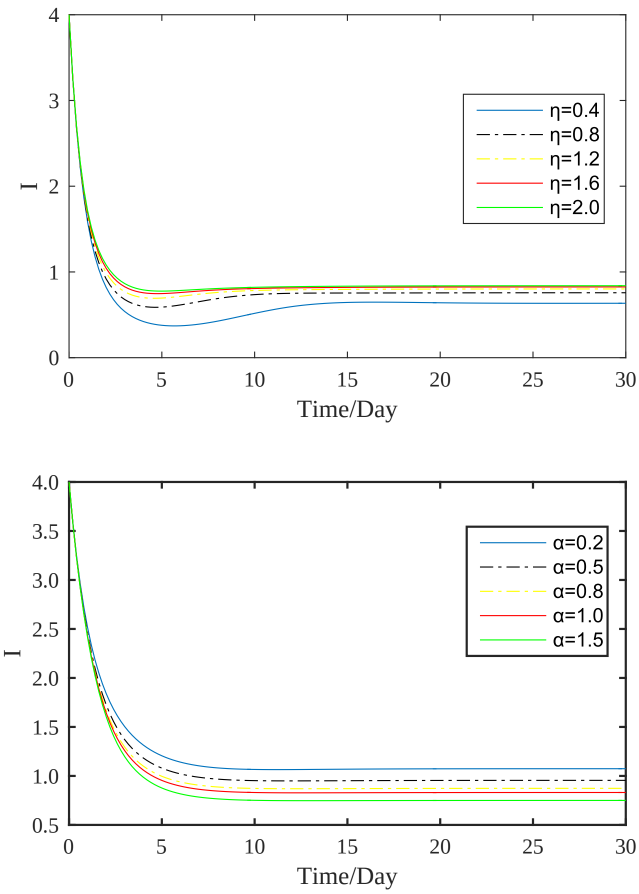


Figure 4. The influence of different values of η and α on the quantity of disseminators.

4. Conclusions

Information spreading begins with the “contact” between people and is affected by the individual's subjective initiative. Based on the classic D-K model of infectious diseases form Daley and Kendall (1965), this study considers the influence of individual psychological effects in the process of rumors dissemination of public emergencies, and establishes a type of rumor dissemination model with nonlinear spreading strength under the individual psychological effects, which is in line with the true psychological state of rumor dissemination. In this paper, by giving the key threshold and discussing the impact of relevant parameters on the spread of rumors, the following conclusions and control measures are obtained:

(1) The spread of rumors presents different evolutionary trends based on different threshold characteristics. If $R_0 \leq 1$, there are only uninformed individuals in the open community, the disseminators and immunizers are removed or vanished; if $R_0 > 1$, the three types of people will coexist in the community (see Figure 2). Thus, for the government departments, it is necessary to pay close attention to the R_0, which is composed of $\lambda, \mu, \gamma, \eta$. Macro measures should be taken to co supervise the spread of rumors from multiple perspectives, such as controlling the flow of people, reducing the "contact" between individuals, timely increasing the channels for pushing authoritative information, etc., so as to regulate R_0 to be less than 1. Otherwise, rumors will last for a period of time, and further measures need to be taken to control them.

(2) The spreading rate of rumors significantly affects the mutual changes among various groups. The larger the value of γ is, the quantity of uninformed and immunized individuals in the community will decrease, while the quantity of disseminators will increase (see Figure 3). Relevant departments can regulate the propagation rate of rumors (γ) in community by taking relevant measures such as strengthening the supervision of the Internet police to shield false information or reduce "contact" between individuals, and timely publishing rumor dispelling information to improve the ability of uninformed people to identify and evaluate information, so as to control the changing trend of the number of the three types of people to a certain extent, and develop toward a benign trend of reducing the proportion of disseminators and increasing the number of immunizers and uninformed individuals.

(3) Individual psychological effects affect the changing trend of the spreading strength of rumors, which in turn changes the quantity of disseminators (see Figure 4). When a public emergency breaks out, government departments or managers should pay attention to the individual's psychology or guide authoritative reporting of events in a timely manner, adjust η and α to improve individual's psychological effects by reducing the people's psychological needs for information or the degree of interest in rumors, and by increasing the degree of attention of the event and the impact of the event itself, etc., so as to reduce the value of η and increase the value of α to improve the psychological effect of individuals, and then intervene and change the final quantity of people who eventually spread rumors.

Just as COVID-19 is still a worldwide pandemic, it's easy to breed some rumors, and the psychological state of local citizens can't be ignored. It is hoped that the results of this study can provide meaningful guidance for the prevention and control of rumors in public emergencies. However, the theoretical model of rumor dissemination built by incorporating individual psychological effects in this research is relatively basic, with some limitations and complex rumor dissemination scenarios to be considered. First of all, this paper only assumes three types of information groups, namely uninformed individuals (S), disseminators (I) and immunizers (R). But in reality, there may be cases that immunized individuals re-infected and spread rumors again, so there will be more than three types of groups, and the transmission routes between groups will be more complex and changeable. In addition, the time lag in the rumor diffusion process may also lead to a certain proportion of potential disseminators, the corresponding model can be constructed in the later stage considering individual psychology. Secondly, for the numerical simulation of this model, we mainly refer to the relevant research data of Wang et al. (2021) and Zhang et al. (2020), and it seems more convincing to capture the real data of typical cases during the epidemic period for targeted simulation and verification. The above areas may be worth further study.

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