

By What Extent the Japanese Has Been Surprised by COVID-19 Information?: Emotional Contagion and its Mathematical Model

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ABSTRACT

A strong field of negative information as the case realized by COVID-19 must greatly enhance the public feelings such as the fear, the disgust and a sense of crisis against it. The information environment regarding COVID-19 and the public reactions to it, which had appeared from the early 2020 to September 2021 in Japan, were first reviewed. The proposition of a mathematical model was followed, where the negative and strong field of information as the issue of COVID-19 was assumed to make the public surprised and their emotions changed negatively via the mechanism of emotional contagion. The frequency of the public access to SNS and Internet under the atmosphere of COVID-19 was considered as a manifestation of the public for seeking reliable information and as an index of the public reaction originated from the negative emotion. By using the time-varying data of the information field of COVID-19, the extent of the public surprise that was considered as the emotional contagion from the field was derived. That extent became clear to have varied heterogeneously with time, having been subjected by the state of information field which have varied with three phases as the initial, transient and quasi-stable ones. It was found that, only in the quasi-stable state of the field, the number of public access to SNS and Internet can mimic the social reality of the issue concerned. Physical and mathematical models, where the psychological phenomena as the emotional contagion are positively included, were pointed out to be central ingredients to understand the behavior of the public in the society more comprehensively than it is today.

Keywords: COVID-19; mathematical model; emotion; emotional contagion; SNS; surprise; information field; news media; Japanese

INTRODUCTION

All the news media such as newspapers and the television make information environment around us. Since people live in such an environment [1,2], they are aware of negative or positive atmospheres of the environment so that they become to be of the same color as the environment though it may be temporary. The sense of people on a certain subject is, thus, determined depending on the quality and the strength of the information environment so that the time variation of the collective sense of people can be said to link with the variation of the information environment through the mechanism of emotional contagion [3-5].

Although the emotional contagion is defined as the propagation of emotion between people [6], we here like to include in it also the propagation and the induction of emotion from the environment to people. A well-known example for the emotional contagion is music, where the environment stimulates public feelings to induce the same sense as itself [7,8]. In the

psychological region some approaches have been done for the quantification of the contagion of various emotions [9,10]. In recent years digital emotional contagion [11] is widely noticed to result in many researches [12-14], where messages brought by digital media or the propagation of emotion between SNS users lead to a specific direction of collective sense.

Also in the region of social physics, a methodology to positively take the emotion into account as a variable has been accepted where the action and the way of thinking of people are treated in terms of the emotion [15-22]. In these approaches the emotion is usually introduced as a function of other variables or treated as a parameter normalized within $[0, 1]$, for instance. Those physical researches are situated at the downstream of information flow from the media to the end, and therefore they are not the ones on the upstream side of the flow where the emotional contagion becomes an issue between the news media and people.

One of the important factors for the effective propagation of information on the upstream is the obtrusiveness of information. In the communication theory it results in whether the information has an agenda setting function or not [23-26], that is, whether it has a particular content topical for people or not. The agenda setting function is weak for an issue which has been reported for a long time when it is compared to a novel issue. For the case of the former issue people have a lot of memory about it so that it lacks of freshness and novelty even if it is new information. It causes feelings of habituation and boredom in people. For the case of an obsolete issue, therefore, much information is required for changing people's mind as compared to a new issue.

The agenda setting effect on a new issue, or in other words the recognition of the significance of the issue becomes maximum around 8-12 weeks after the exposure of information, and decreases after 12-25 weeks [27]. For the assessment of this effect it must evaluate the strength of the impact of exposure which has not been studied quantitatively, although in the past the extent of the exposure has been quantitatively counted by the number of articles in newspapers or the broadcasted time on the television. For the strength of agenda setting effect, it is also pointed out the importance of the treatment of information by statistically taking into account the prominence of the issue such as the size of title [23] for instance, but any researches have also been done quantitatively. Watt, Mazza and Snyder [23] show, in relating the information environment to people, that the following four factors become important for people's cognition of information; (1) memory of information, (2) habituation to the issue, (3) delay of people's reaction or the so-called attitudinal inertia and (4) selective attention toward a specific information.

In the case when a specific emotion propagates through the society from the news media to the end and the people's view of values is influenced by that emotion [28], we can simply depict its aspect as in Fig.1. Emotional resonance by music corresponds to the process 4) in this figure, and the propagation of rumor with emotion and the influence of emotion in various social activations correspond respectively to 5.1) and 5.2). The study by Wheaton, Prikhidko and Messner [29] is a research of emotional contagion regarding COVID-19 on such an upstream side by a psychological approach. Researches including modeling on this side have been forced to be phenomenological mainly because of the lack of reliable numerical data. In this paper the processes 3) and 4) on the upstream side in Fig.1 is mathematically modeled by using the data

of COVID-19 in Japan to exemplify the emotion which has been treated only implicitly in physical sciences.

In Section 2 the statistics are shown for the information environment on COVID-19 in Japan up to the end of September 2021. In Section 3 the social atmosphere and the time variation of people's emotion regarding COVID-19 are shown. A simple mathematical model and its example calculation are given in Section 4. By using this model, the emotional contagion factor is derived in Section 5, which is our index to indicate by what extent people's emotion is affected by the contagion from the COVID-19 information. Conclusion is given in Section 6.

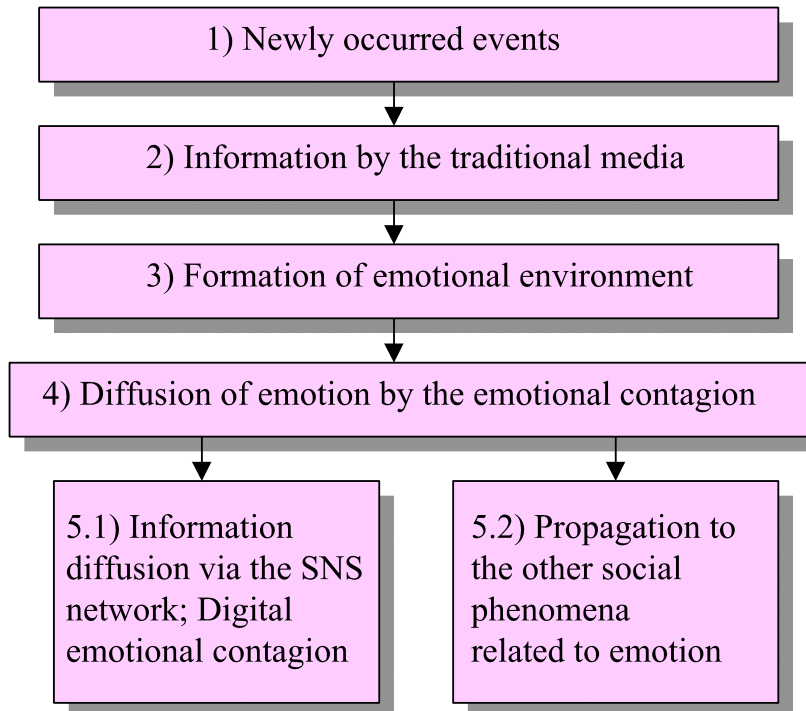


Fig.1. Schematic diagram for the relation between the public and emotion

INFORMATION ENVIRONMENT OF COVID-19 AND JAPANESE REACTION ON SNS

In this paper we set 1 January 2020 as $t=1$ and use a unit of time $\Delta t=1$ [day] from $t=1$ to 30 September 2021 ($t=639$). In 2020 the news media to which the Japanese access for getting news once or more per week are (1) the television (of which 74.5% of the Japanese make use), (2) Web sites (54.7%), (3) newspapers (46.1%), and (4) the SNS (36.8%) [30]. We divide the information released by the television and newspapers as the primary one for which they cover events to get their originality, and the secondary information released from the remaining media except for them. In what follows we quantitatively investigate how the primary information on COVID-19 has been released with time after January 2020 in Japan.

Fig.2(a) shows the time variation of the number of patients infected by COVID-19 per day [31], $d(t)$, and its moving average over the past one week $D(t)$. Here the quantity $D(t)$ is defined as

$$D(t) \equiv N \sum_{t'=0}^6 f_{t'} \cdot d(t-t') \quad (1)$$

where N is a normalization constant and f_t is a weight which is assumed as $f_t=1/7$, for simplicity. Fig.2(b) shows the “street crowds” [54] and its moving average. This gives the time variation of the average number of people per hour observed near a scrambled crossing at Shibuya in Tokyo, together with the four periods of the declaration for a state of emergency.

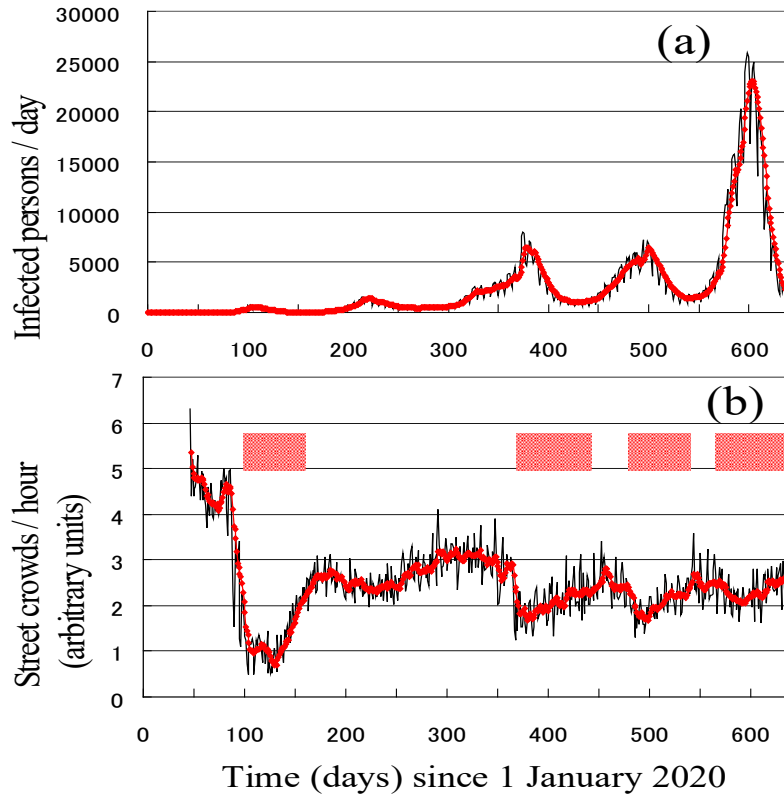


Fig.2. (a) Time variation of the number of infected people per day by COVID-19 in Japan in black solid lines, and its moving average during the past one week in red dots; (b) Time variation of the average number of street crowds per hour observed at Shibuya in Tokyo. Red dots are the moving average and red-shaded rectangles represent the periods of a state of emergency in Tokyo

On the other hand Fig.3(a) shows the time variation of the number of television programs on COVID-19 broadcasted per day from NHK that is a unique TV station covering the whole country [32]. Those are the programs with key words containing the spelling “corona” in Japanese, having a rather sharp peak at $t\sim 120$ and a second peak which is broad at around $t\sim 350$. Since it is difficult to obtain information from the other TV stations except for NHK, we assume it to be similar to this figure, for simplicity.

Three major newspapers which distribute throughout the whole country in Japan are (1) the Yomiuri (82.7 thousands of circulation per day in 2020) [33], (2) the Asahi (56.5 thousands) [34], and (3) the Mainichi (25.0 thousands) [35]. Figure 3(b) shows the time variation of the number of articles with a key word “corona”, which was derived by averaging three newspapers with the weight of the circulation. Although its overall feature is quite similar to Fig.3(a), it has sharp minima with periods of one week and one month which correspond to the periods of newspaper holidays. Figure 3(c) shows the time variation of the primary information on

COVID-19 averaged by the television (with a weight $74.5/(74.5+46.1)=0.62$) and newspapers (with a weight $46.1/(74.5+46.1)=0.38$), $i_{env}(t)$, together with its moving average over the past one week. The feature of Figure 3(c) is quite different from the distribution of infected patients, Fig.2(a).

In the everyday life people catch the primary information and take actions to it, empathizing with its significance and novelty. The primary information regarding to COVID-19 has always been negative so that it has induced emotions such as anxiety, antipathy, fear, and discomfort in people's mind. We can say that those emotions have grown in people through the mechanism of emotional contagion from their environment. Those emotions have appeared to the fore in various forms of public reactions. Here we study the frequency of access to the SNS as a form of the reaction.

Figure 3(d) shows the time variation of the number of Twitters (red lines) communicated per day within all sites with a key word "corona" in Japanese [36], along with the number of Google search (by black lines) performed per day regarding Japanese words containing "corona" [37], both numbers being normalized as 100 at $t=99$ (8 April). Almost Japanese use Twitter for the confirmation and exchange of information, whereas the Internet search as the Google search is to make up for the insufficient condition of information. Two types of lines in Fig.3(d) are quite similar to each other, indicating that people have simultaneously executed Twitter and Internet search at the same time. If those responses on the SNS were stimulated and induced directly by the information field, it is quite peculiar that the time behavior of the lines in Fig.3(d) is clearly different from the one in Fig.3(c).

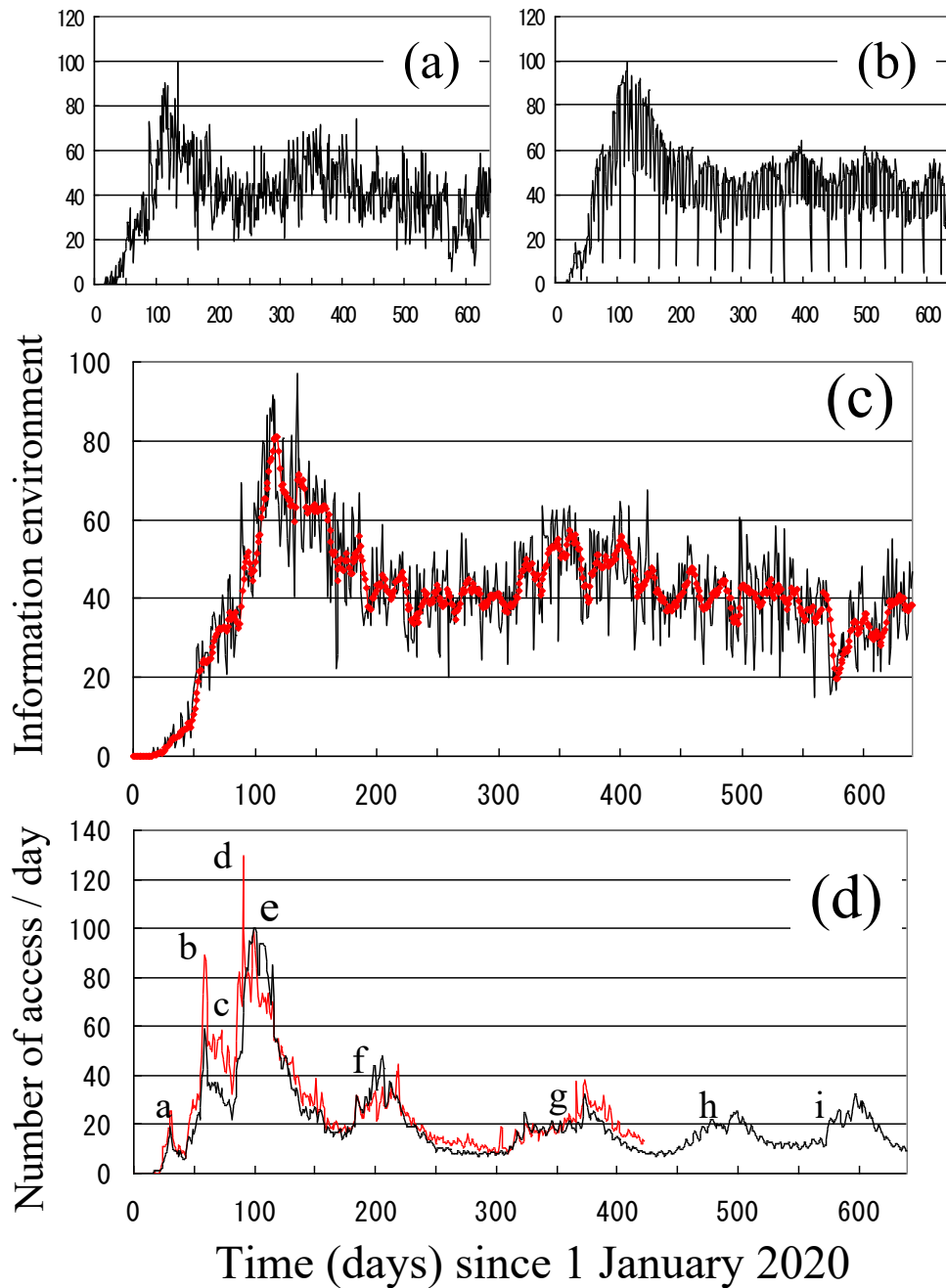


Fig.3. (a) Time variation of the amount of information released by the television NHK in Japan regarding "corona"; (b) Average amount of information released by newspapers. Normalization was made so that the maximum amounts in both (a) and (b) are 100; (c) Average amount of information by the traditional media of the television and newspapers. Red dots are the moving average during the past one week; (d) Time variation of the number of public access per day to the SNS where normalization was made as 100 at $t=99$. Red solid lines: Twitter, and black solid lines: Google search. Refer to the text for the peaks $a\sim i$.

Although the two types of access lines given in Fig.3(d) seem to show the similar time trend, they are different in detail from each other. Such difference may be due to the difference between the ages of people who use Twitter and Internet search. When we roughly assume the

people who make the Internet search as the Smart-phone user, they account for 90.4% of teenagers, 83.3% of the age 60s and 71.9% of the 70s [30]. On the other hand the users using Twitter distribute from 78.2% of teenagers to 12.8% of the age 70s, leaning overwhelmingly toward young people [30]. Moreover there exists observation that the majority of women of the age 10~20 accesses Twitter everyday but for the user over 30s the everyday access is less than 30% [30]. The emotional contagion and its reaction have dependence on the age and the gender, and hence it is natural for the distributions of Twitter and Google search to be different in details as seen in Fig.3(d).

The possibility that the number of Internet search becomes to be an indicator which reflects, to some extent, the collective recognition and the cognitive state of the society has been pointed out [38-42]. Taking the above all into account, we treat the number of the Google search given in Fig.3(d) as a representative index for the people's reaction to the information field.

TIME VARIATION OF SOCIAL BACKGROUND AND COLLECTIVE EMOTION

Little had been reported about COVID-19 from the traditional news media up to 15 January 2020, at which time an ordinary flu had been raging in Japan and many patients suffered from it. Although on 16 January ($t=16$) newspapers and the television extensively reported about the first outbreak of COVID-19 in Japan, there was no information available for the measures to deal with it at that time and every news papers released reports such that the Ministry of Health, Labor and Welfare could not keep up with that situation. On every day after 17 January ($t=17$) the news media extensively reported about the expansion of the contagious disease which was suspected as Chinese origin, the non-existence of any effective means against it, the gradual increase of death in China, the countermeasures taken in China such as the restriction of movement of people and the ban of domestic travel, and the appearance of the dead also in other countries. In this period the fear against the unknown virus was rapidly enhanced in the public [43] (At around the same time the similar trend as that in Japan appeared in other countries [44]). Therefore to defend themselves from it, a few people released on the SNS the opinions about the exclusion of the Chinese and the Chinese merchandise, and fake news about the entry of many Chinese travelers into Japan. Those subjects were sensationally reported from some television stations and many people sided with them so that the communication rapidly enhanced on the SNS (Peak *a* in Fig.3(d)) [45,46]. Such a trend continued even in the early February so that the news media appealed to the public to take rational behavior.

In the mid February, the rate of people who were worried about the new type pneumonia amounted to 82% [47]. During about one month from the mid January to the mid February, the feeling of people's disgust against COVID-19 was quite strong [43]. Also in the mid February, all elementary, junior high and high schools in the whole country were determined to be temporarily closed. Since raw materials for sanitary supplies were imported from China, information on the lack of those commodities together with other information which denied that information became complicated, and it occurred a panic state again on the SNS in the late February (Peak *b*) [48]. People's fearfulness was enhanced by the successive occurrence of death and infected patients, and the Government requested the elementary and junior high schools in the whole country to move up the spring vacation and adjust the beginning of a new school semester. This rather caused social confusion and people's communication on the SNS never decreased in this period (region *c*). At the end of March a celebrity died suddenly by the contagion of COVID-19, whose news brought people strong amazement and, further and

rapidly, caused people's worry and fear increased (peak *d*) [49]. The Government announced on 7 April ($t=98$) the state of emergency for seven administrative divisions including Tokyo, and asked people to reduce the mutual contact by at least 70% or 80% as much as they can. Since such an announcement was the first time for people to experience, they became greatly confused to result in the sharp increase of communication via the SNS along with the number of Internet search (peak *d*). On 22 April a famous actress also died by the infection of this virus, its reaction appearing as a peak *e* on the SNS although it is not so remarkable because of the overlap of the decreasing part of the peak *d*.

In July 2020, the number of infected patients continued to increase, updating maximum every day, and the second wave of the spread of the virus came to appear. Although the people's feeling of impending crisis became somewhat weaker compared with that in the first wave, people still held strong fearfulness and anxious feeling against COVID-19 [50,51]. These correspond to a broad peak in July and August (peak *f*, $t=180\sim 230$). Since throughout this period the news media continued to inform of the propagation of COVID-19 over the world every day, people's sense of crisis never came to fade. Practical countermeasures for the prevention of the virus along with the care of the infected patients were almost in a powerless state at around that time, and these also caused people to sustain the fearful feeling.

The increase of the number of access to the SNS (peak *g*) appearing from November 2021 to January 2021 was due to the media report regarding the third-time increase of infected patients and the second declaration of a state of emergency (8 January 2021: $t=374$). The declaration was enlarged for four administrative divisions on 25 April ($t=481$), for six divisions on 12 May ($t=498$), for 9 divisions on 16 May ($t=502$), and ten divisions on 23 May ($t=509$). Around those times people's sense of crisis and nervous feeling against COVID-19 seemed somewhat relaxed [52,53] but the peak still appeared on the SNS (peak *h*) though its strength was weakened as compared with the before.

In July 2021 the rate of people who were concerned about the spread of Corona virus with the open of 2020 Tokyo Olympic and Paralympic Games, which were respectively scheduled from 23 July 2021 ($t=570$) and 24 August 2021 ($t=602$), became to increase. In the early July, about 65% of people thought that the Games could not be held safely and securely, and 66% of people thought that the new declaration of a state of emergency could not effectively work⁵⁵. Although the fifth attack of the virus was quite severe and the television had released critical messages every day in August and September, people's reaction (a broad peak *i*) was only around the former one because they became to be accustomed to the lifestyle "with corona".

The broad peaks *g*, *h* and *i* is constituted from medium-level sub-peaks, each of which originated from unexpected increase of the number of patients and the declaration of a state of emergency. This is because those topics had been seriously informed by the news media each time when they occurred, which caused people's feeling negative every time. Such strained feeling of people can also be inferred from the "street crowds" which was already given in Fig.2(b). If the decrease of the crowds was due to the increase of the people's feelings of crisis, fearfulness and disgust against COVID-19 (and vice versa), this figure indicates that such feelings were rapidly distributed in the society after April 2020 ($t=92\sim$) but decreased their intensities in October-November ($t=275\sim 335$). In 2021 ($t=367\sim$) they repeatedly increased and decreased ($t=485\sim$)

again to get to the end of September 2021. Such a pattern of people's movement roughly corresponds to the emergency declaration.

EMOTIONAL CONTAGION MODEL

We presume here that the time variation of the frequency of Google search shown in Fig.3(d) is just a manifestation of the people's negative feelings such as anxiety or fear against COVID-19. In what follows we show a model for the emotional contagion from an information field to people by connecting the time varying feelings of people with the variation of information environment.

Mathematical Model

When people intend to make mutual communication via the SNS or the Internet search on a specific subject after receiving obtrusive news that they feel to be significant, its motivation is mainly due to supplement the news and to make sure of it by obtaining more reliable information. In the case when the frequency of those activations via the SNS or the Internet (setting this variable as x) closely relates to the strength of information field (setting the strength as y), considering the activations to be stimulated by the field, the quantities x and y are expected to be similar in their time behaviors to each other. In the case of COVID-19, however, there exist no correlations at first sight between them as seen in Figs.3(c) and 3(d). This indicates an existence of several intervening processes between x and y . Here we set the following five presumptions.

(1) The people's motivation to access SNS and Internet after being stimulated by the information field is to supplement and to certify insufficient and uncertain information. Under an ordinary condition without such a motivation, the source term regarding the time variation of x becomes null. Namely

$$\frac{dx}{dt} = -c_1 \frac{x}{\tau} + (\text{source term}) \quad (2)$$

where c_1 is a constant and τ is a time scale for the x to vary. In the case without any source terms, the x is assumed to decrease in an exponential manner, for simplicity [23].

(2) The people's emotion ξ ($\in [0, 1]$) is assumed to be proportional to the variable x .

$$\frac{d\xi}{dt} \propto \frac{dx}{dt} \quad (3)$$

where $\xi=1$ (or 0) corresponds to the maximum state (or utterly indifferent state) of emotion regarding the issue concerned. People are assumed to instinctively perceive negative feelings in the atmosphere such as antipathy, fear, anxiety, or distrust, which cause their reactions via the SNS and the Internet. Through the exchange of information and feelings via the SNS, the feelings further propagates and is homogenized in the society to result in an appearance of collective emotion common to all.

(3) According to the traditional theory of news media, the more obtrusive (the more fresh and the more conspicuous) the information is regarding the issue, the higher the extent of impact that enhances the emotion of people is [23]. Hence in this case the source term is to be proportional to the novelty of information.

On the other hand, the novelty of information is also dependent on how long time the issue has been the topic among people, in other words, on the amount of information memorized by people up to that time [23]. This is because, with the increase of people's memory regarding the issue, people become to feel sufficiency of information and the extent of their surprise decreases. This process is the experience or the habituation for similar information so that it is considered a sort of learning process for a specific information. The novelty of information at t , $\varepsilon(t)$, is assumed, therefore, to be given by the learning curve, Sigmoid function, or its approximate form of an exponential function as:

$$\varepsilon(t) \approx \exp(-\gamma Z(t)) \quad (4)$$

where γ is a constant, and $Z(t)$ is the amount of information of the issue memorized by people

$$Z(t) = c_2 \int_0^t I_{env}(t') \cdot \omega(t', t) dt' \quad (5)$$

where c_2 is a constant, $I_{env}(t)$ is the strength of the information field at t which is assumed to be proportional to the amount of information released by the news media at t , and $\omega(t', t)$ is the fraction of the information released at t' , which remains to be memorized by people until t . The $\omega(t', t)$ is called the oblivion or forget function.

(4) With regard to the form of the function $\omega(t', t)$, either of the power form or the exponential form of the variable t have been applied. In what follows the following exponential form is used to reduce the number of parameters [1].

$$\omega(t', t) = g \cdot \exp\left(-\frac{(t-t')}{t_0}\right) + (1-g) \quad (6)$$

where g and t_0 are constants. The quantity g is the fraction by which people finally forget information.

(5) When people are stimulated by a certain exciting issue in the information field, the source term in Eq.(2) becomes to be proportional also to the strength of information field $I_{env}(t)$, together with the extent of the emotional contagion from the field $\Delta(t)$ at time t . The factor $\Delta(t)$ seems to be roughly proportional to the strength of impact of the field on people at least within a certain range of its strength. The extent of emotional contagion, however, must be saturated under a strong impact, and moreover there may be a sort of threshold of impact for the contagion to appear. Hence the quantity $\Delta(t)$ does not simply correspond to the strength of impact so that we call the $\Delta(t)$ as the emotional contagion factor, hereafter. The larger value of $\Delta(t)$ corresponds to the greater extent of the emotional contagion. Taking also the novelty of information $\varepsilon(t)$ into account, the source term is given by:

$$\text{source term} \propto \varepsilon(t) \cdot I_{env}(t) \cdot \Delta(t) \quad (7)$$

where $\Delta(t) \geq 0$.

Figure 4 is the schematic diagram for the emotional contagion. When $\xi(0)=0$, we obtain, from equations (2)~(7), the following solution for the emotion $\xi(t)$.

$$\xi(t) = C \int_0^t \varepsilon(t-t') \cdot I_{env}(t-t') \cdot \Delta(t-t') \cdot \exp(-t'/\tau) dt' \quad (8)$$

where C is a constant.

Differentiating the left hand side of Eq.(2) as $dx(t)=\{x(t+1)-x(t-1)\}/2$ and solving for the emotional contagion factor we further obtain:

$$\Delta(t) = \text{MAX} \left[\frac{1}{2C' \cdot I_{env}(t) \cdot \varepsilon(t)} \left\{ x(t+1) - x(t-1) + \frac{2}{\tau} x(t) \right\}, 0 \right] \quad (9)$$

where C' is a constant, $x(t)$ is the substitute for the people's emotion $\xi(t)$ which in our case the number of access to the SNS per unit time, and $\text{MAX}[a, b]$ is the maximum of either a or b .

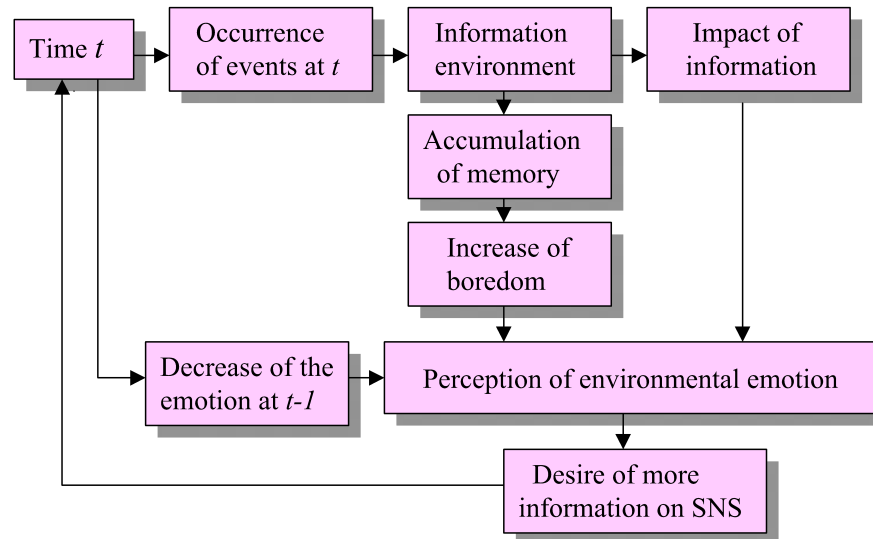


Fig.4. Schematic diagram for the model of emotional contagion.

Determination of Constants and Example Calculation

Here we try to reproduce the time-dependent number of Google search given in Fig.3(d), which we consider as the people's reflection representing the negative emotion against COVID-19, by using the time-varying information field given in Fig.3(c).

Since, according to Fig.3(d), the number of access to Google search has local peaks at $t=30,58,100,106,205,324,373,499$ and 597 , this indicates that the people's emotion was stimulated at around those times by the emotional contagion from the field. With a simple assumption that the source term in Eq.(2) has a finite value only at the following seven times $t=t_0 \equiv 30, 51, 91, 199, 324, 479$ and 583 , we set $\Delta(t)=\delta(t-t_0)$, where $\delta(t)$ is the delta function so that $\Delta(t)=1.0$ and 0.0 in the cases of $t=t_0$ and $t \neq t_0$, respectively. The emotional contagion factor is thus assumed as 1.0 or 0.0 , which are only trial values to determine unknown constants. The values of several constants in Eq.(8) are fixed by comparing the model calculation $\Xi(t)$ with the real value $\xi(t)$ given in Fig.3(d) so as to the following quantity χ^2 becomes minimum:

$$\chi^2 \equiv \sum_{t=1}^{t_{max}} \{\Xi(t) - \xi(t)\}^2 \quad (10)$$

where t_{max} is the maximum time $t=639$.

The model calculation $\mathcal{E}(t)$ thus derived together with the features of $\varepsilon(t)$ and $Z(t)$ are respectively shown in Figs.5(b) and 5(a), where the values of constants are $C=8.06$, $\tau=24.9$, $\gamma=2.50 \times 10^{-3}$, and $t_0=17.0$ in a unit of day for time and $g=1.0$. Although the $\mathcal{E}(t)$ can be said to roughly reproduce the real feature of Fig.3(d), its details are clearly different from that. This is due to the assumption that the emotional contagion factor was simply set as $\Delta(t)=\delta(t-t_0)$, which seems not to be appropriate. In the next section we study the time-dependent behavior of the emotional contagion factor.

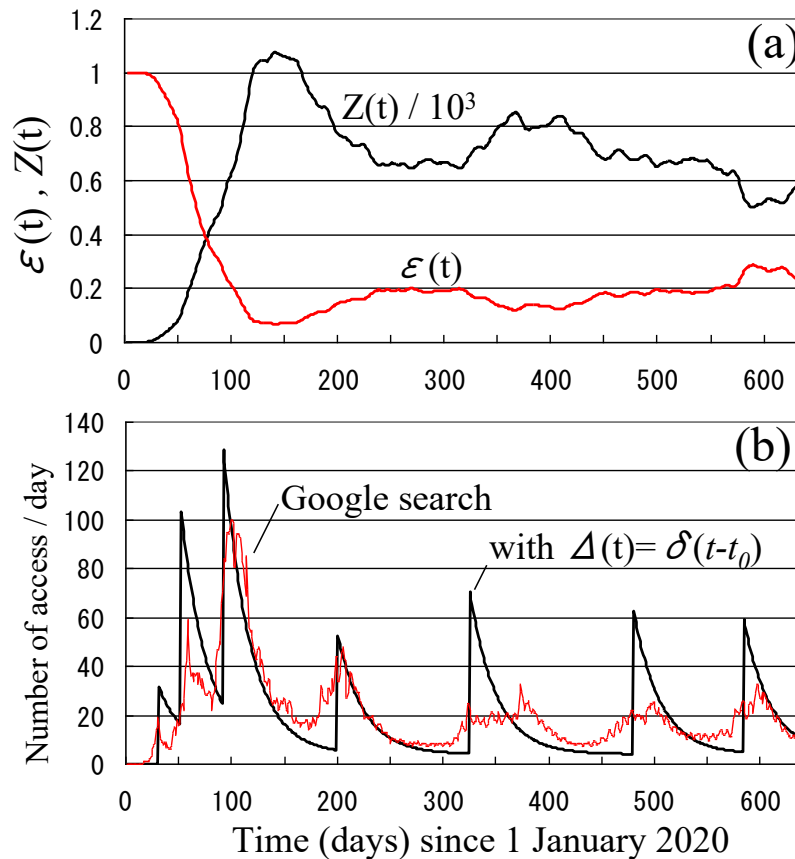


Fig.5. (a) Time variation of the novelty of information $\varepsilon(t)$ and the amount of information memorized by people $Z(t)$; (b) Comparison of the model (in black solid lines) and Google search (in red solid lines given in Fig.3(d)). An assumption was made in the model calculation as $\Delta(t)=\delta(t-t_0)$. Refer to the text for the constant t_0 .

BY WHAT EXTENT HAS THE JAPANESE BEEN SUBJECTED TO THE EMOTIONAL CONTAGION FROM THE COVID-19 INFORMATION

Using the constants determined in the previous section and setting $C'=C$, the emotional contagion factor $\Delta(t)$ derived from Eq.(9) is shown in Fig.6(a) and its moving average over the past one week in Fig.6(b). The $\xi(t)$ derived by using Eq.(8) with such $\Delta(t)$ together with the values of constants above cited can well reproduce Fig.3(d) as a matter of course (and therefore it is not shown here). The extent of the emotional impact that people have received is just proportional to the emotional contagion factor shown in Figs.6(a) and 6(b). We should note here that the $\Delta(t)$ do not give a certain absolute value but just a relative value representing people's surprise at a time t .

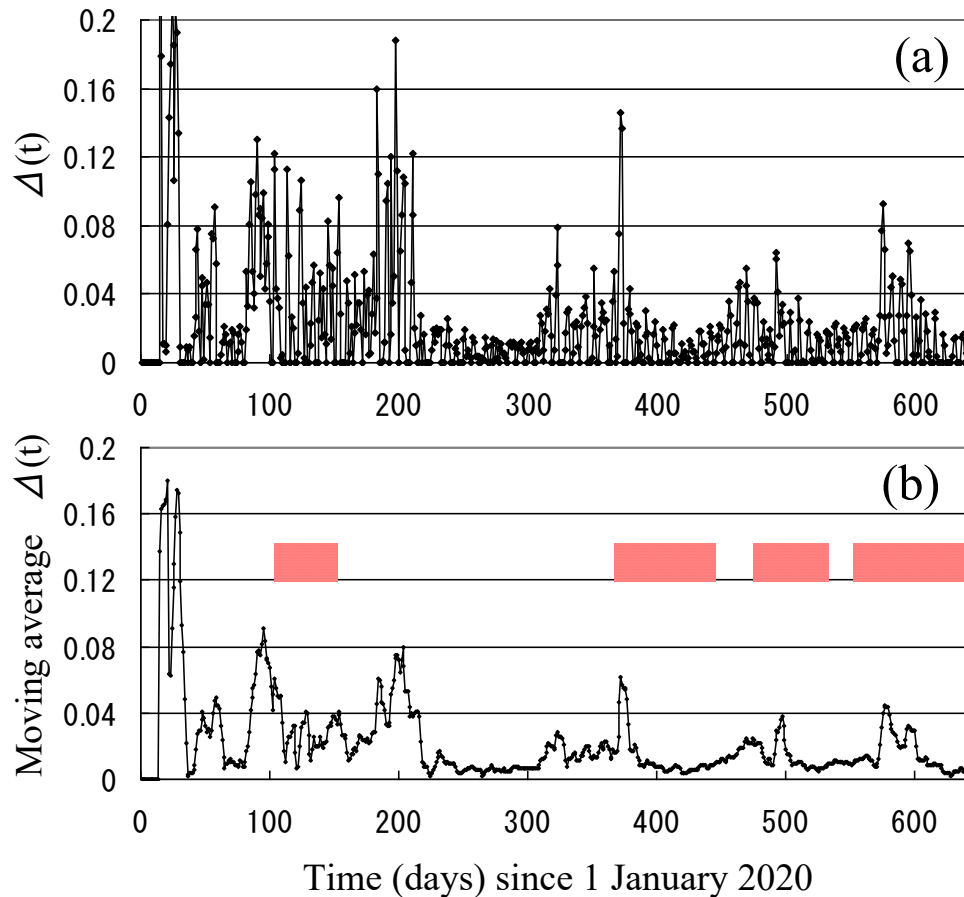


Fig.6. (a) Time variation of an indicator for the extent of the emotional contagion, the emotional contagion factor $\Delta(t)$; (b) Moving average of the $\Delta(t)$ during the past one week. Red-shaded rectangles represent the periods of a state of emergency in Tokyo.

From Figs.6(a) and 6(b) the emotional contagion becomes clear to have taken place, not with a constant rate nor at random with time, but rather in such a manner as having a meaningful value of $\Delta(t)$ at each time whose trend is as follows.

The $\Delta(t)$ has a unique value at $t=16$ which seems abnormal as $\Delta = 0.963$ (and hence it is out of the ordinate in Fig.6(a)), together with high values at $t=23\sim 30$ where $\Delta \approx 0.2$. On 16 January 2020 ($t=16$) when newspapers and the television reported the first breakout of the infected patient of COVID-19, there did not exist almost any information on COVID-19 nor the information to offer on its countermeasures to result in the empty response by the Ministry of Health, Labor and Welfare. This caused strong feelings of fear, antipathy and anxiety in people's mind to give rise to the sudden occurrence of Twitter communication and Google search on the Corona although they do not remarkably appear in Fig.3(d) due to their small values. This implies that the beginning of a rumor is caused by a great surprise of people whose number is quite small. This is just the first manifestation of the emotional contagion from the information field to people. Almost the same situation arose at $t=25\sim 30$ under a little more information along with a newly occurred issue of mass infection on a cruise ship Diamond Princess in Yokohama.

During a time span $t_1 < t < t_2$ where $t_1 \approx 30$ and $t_2 \approx 150$, the $\Delta(t)$ has peaks at the same time as the maximums of Twitter and Google search together with other small peaks around them. The latter small peaks seem to originate from several unexpected issues which occurred during this period as described in Sect.4. The $\Delta(t)$ in this period did not so strong as we expect from the time behavior of Twitter and Google search in Fig.3(d).

After the time $t = t_2$, the time-varying feature of $\Delta(t)$ becomes to resemble to Google search so that the number of access to the SNS indicates the extent of the people's feelings disturbed by the emotional contagion from the field. Such resemblance between the two variables implies that the strength of information environment $I_{env}(t)$ become almost stable in this period and that the feature of $\Delta(t)$ is almost determined depending on whether or not there exist something new and obtrusive contents in the information such as the declaration of a state of emergency. Thus we can divide the time behavior of $\Delta(t)$ into the following three phases, where $t_1 \approx 30$ and $t_2 \approx 150$ in our case:

- (1) Initial phase ($t < t_1$): The $\Delta(t)$ had large values at every time when the news media released information on COVID-19 since people experienced the Corona at the first time, being surprised by its unknown reality. Their surprise lead fear, antipathy and anxiety in their mind. This phase corresponds to the beginning of the expansion of rumors.
- (2) Transient phase ($t_1 < t < t_2$): During this phase, people were continuously surprised by the successive occurrence of unexpected events about which some television stations exaggeratedly reported its seriousness. Hence the $\Delta(t)$ had medium values though the frequency of the people's access to the SNS was high.
- (3) Quasi-stable phase ($t_2 < t$): Since people became to be accustomed by the information field, the $\Delta(t)$ has relatively small values. The period of $t > t_2$ can be called as a quasi-stable phase in the meaning that the number of the people's access to SNS was almost proportional to the people's surprise. The rise of $\Delta(t)$ at some times in this period was due to the people's nervousness originated from external events such as the declaration of a state of emergency.

Thus our model have revealed that the emotional contagion from the environmental field of COVID-19 to people has occurred heterogeneously in time, that the time high in the emotional contagion is just the time of the initial phase of the COVID-19 issue and of the infected patients rapidly increased, when the news media had no information available for countermeasures to it but loudly cried its critical state. Political measures such as the declarations of a state of emergency were also found to have caused people to be more nervous and to result in the state of stronger awareness to COVID-19.

Since the time behavior of $\Delta(t)$ is related not only to the strength of information field but also to the novelty of information and people's experience to it, the number of access to the SNS does not always mimic the people's emotion. It is only the quasi-stable phase above described that the proportionality holds between the number of people's access to SNS and the extent of people's surprise, i.e., the significance of a certain social issue. Since the threshold time t_2 depends on the issue, the feature of the information environment, people's culture, people's sensitivity together with many other factors, it is difficult to determine whether it is the right time t greater than t_2 to apply the proportionality [38-42]. Generally speaking, in the case when we intend to search a certain social reality by using the so-called big data, we should note the

fact that so many factors intervene between the data and the reality such as the social, cultural and information environments along with people's psychological sensitivities. We are required, therefore, to introduce a comprehensive model to understand the relation between the data and the reality in those cases.

A long-range trend of $\Delta(t)$ from the early 2020 is noted that it seems to gradually decrease its strength with time as seen in Fig.6(b). This is a reasonable behavior from the viewpoint of communication theory such that the salience people feel on an issue decreases with increasing the experience of the issue under similar information. In fact in the quasi-stable period, people have complained of "mental fatigue due to Corona" and "physical fatigue due to self-restraint", and hence the rate of people has become increased after 2021 who intend to drive COVID-19 away from their concern [52,53].

CONCLUDING REMARKS

In this paper the time variation of the number of access to the SNS under the social environment of negative feelings such as fear, antipathy and anxiety was assumed as a manifestation of the negative feelings of people, which was caused by the emotional contagion of the feelings from the environment to people. A model for such emotional contagion was proposed and investigated for the case of COVID-19 in Japan as an example, where assumed was that the rapid increase of the access to the SNS was a manifestation of the people's awareness for seeking new reliable information and for making sure of uncertain information. Such access to the SNS, therefore, was considered to originate from the surprise by the feelings as fear, antipathy and anxiety which propagate from the information field to people via the emotional contagion.

The extent of emotional contagion derived by our model was found to be consisted from three phases of initial, transient and quasi-stable ones. In the former two phases the extent of people's reaction in the society such as the access to the SNS is not proportional to the extent of emotional contagion. The traditional interpretation of the public response on the SNS [38-42] in relating it to the social reality, therefore, should be noted to hold good only for the case of the quasi-stable phase of the emotional contagion.

It also became clear that the variables difficult in quantification such as the people's feeling can be quantified by replacing it with some statistical value, such as the number of access to the SNS under a certain condition, for instance. By positively introducing the emotion as a variable into a model, we can treat the people's feeling as a trustable variable in the model, which have been almost treated as a parameter in the past. Thus by doing so, we may understand the psychology-related behavior of the public in the society by using physical and mathematical models more profoundly and more comprehensively than that in the past.

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References

- [1]. Ohnishi, T. and K. Shimano, Public interest immersed in the field of information environment: How has Japanese interest in energy and environmental problems varied?, *Reports in Advances of Physical Sciences* 2(1) (2018) 1850005.
- [2]. Ohnishi, T., Can interactive dual field of information explain the prevalent phenomena, *American J. Physics and Application* 7(6) (2019) 144-155.
- [3]. Epstein, J.M., J. Parker, D. Cummings, et al., Coupled contagion dynamics of fear and disease: mathematical and computational explorations, *PLoS ONE* 3 (2008) e3955.
- [4]. Kramer, A.D.I., J.E. Guillory, and J.T. Hancock, Experimental evidence of massive-scale emotional contagion through social media, *PNAS* 111 (2014) 8788-8790.
- [5]. Ferrara, E. and Z. Yang, Measuring emotional contagion in social media, *PLoS ONE* 10(11) (2015) e0142390.
- [6]. Hatfield, E., J.T. Cacioppo, and R.L. Rapson, *Emotional Contagion* (Cambridge Univ.Press, New York, 1994).
- [7]. Aiello, R. and J.A.Sloboda (ed), *Musical perceptions* (Oxford Univ. Press, 1994).
- [8]. Juslin D.N. and J.A. Slboda (ed.), *Music and emotion: theory and research* (Oxford Univ. Press, 2001).
- [9]. Doherty, R.W., The emotional contagion scale: a measure of individual differences, *J. Nonverbal Behavior* 21 (1997) 131-154.
- [10]. Bispo, J. and A.Paiva, A model for emotional contagion based on the emotional contagion scale, *Conference paper of the 3rd International Conference on ACII 2009*, <https://ieeexplore.ieee.org/document/5349396> (1 July 2021 retrieved).
- [11]. Goldenberg, A. and J.J. Gross, Digital emotion contagion, *Trends in Cognitive Sciences* 24 (2020) 316-328.
- [12] Zhao, L., J. Wang, R. Huang et al., Sentiment contagion in complex networks, *Physica A* 394 (2014) 17-23.
- [13]. Fan, R., K. Xu, and J. Zhao, An agent-based model for emotion contagion and competition in online social media, *Physica A* 495 (2018) 245-259.
- [14]. Sasaki, W., Y. Nishiyama, T. Okoshi, et al., Investigating the occurrence of selfie-based emotional contagion over social network, *Social Network Analysis and Mining* 11 (2021) 8.
- [15]. Hill, A.L., D.G. Rand, M.A. Nowak, et al., Emotions as infectious diseases in a large social network: the SISa model, *Proc. Roy Soc. B* 277 (2010) 3827-3835.
- [16]. Tsai, J., E. Bowring, S. Marsella, et al., Empirical evaluation of computational fear contagion models in crowd dispersions, *Auton. Agent Multi-Agent Syst.* 27 (2013) 200-217.
- [17]. Cao, M., G. Zhang, M. Wang, et al., 2017, A method of emotion contagion for crowd evacuation, *Physica A* 483 (2017) 250-258.
- [18]. Ta, X-H., B. Gaudou, D. Longin, et al., Emotional contagion model for group evacuation simulation, *Informatica* 41 (2017) 169-182.
- [19] Jiang, S. and H. Fan, Credit risk contagion coupling with sentiment contagion, *Physica A* 512 (2018) 186-202.
- [20]. Zeng, R. and D. Zhu, A model and simulation of the emotional contagion of netizens in the process of rumor refutation, *Scientific Reports* 9 (2019) 14164.
- [21]. Ni, X., H. Zhou, and W. Chen, Addition of an emotionally stable node in the SOSa-SPSa model for group emotional contagion of panic in public health emergency: implication for epidemic emergency responses, *Int. J. Environ. Res. Public Health* 17 (2020) 5044.
- [22]. Guo, X., J. Tong, P. Chen, and W. Fan, The suppression effect of emotional contagion in the COVID-19 pandemic: A multi-layer hybrid modelling and simulation approach, *Plos ONE* 16(7) (2021) e0253579.
- [23]. Watt, J.H., M. Mazza, and L. Snyder, Agenda-setting effects of television news coverage and the effects decay curve, *Communication Res.* 20 (1993) 408-435.

- [24]. Doyle, C., B.K. Szymanski, and G. Korniss, Effects of communication burstiness on consensus formation and tipping points in social dynamics, *Phys.Rev. E* 95 (2017) 062303.
- [25]. Zheng, Z., H. Yang H., Y. Fu et al., Factors influencing message dissemination through social media, *Phys. Rev. E* 97 (2018) 062306.
- [26]. Yi, Y., Z. Zhang, and C. Gan, The outbreak threshold of information diffusion over social-physical networks, *Physica A* 526 (2019) 121128.
- [27]. Salwen, M.B., Effect of accumulation of coverage on issue salience in agenda-setting, *Journalism Quarterly* 65 (1988) 100-106.
- [28]. Steinert, S., 2020, Corona and value change. The role of social media and emotional contagion, *Ethics and Information Technology*, <http://doi.org/10.1007/s10676-020-0945-z> (1 July 2021 retrieved).
- [29]. Wheaton, M.G., A. Prikhidko, and G.R. Messner, Is fear of COVID-19 contagious? The effects of emotion contagion and social media use on anxiety in response to the Corona virus pandemic, *Front. Psychol.* 11 (2020) 567379.
- [30]. NTT Docomo Mobile Shakai Kenkyuusho (ed.), Mobile utilization trends 2020-2021: a mobile society white paper (Chuuou Keizai Sha, Tokyo, 2020) (in Japanese).
- [31]. NHK, <https://www3.nhk.or.jp/new/special/coronavirus/data-all> (8 September 2021 retrieved).
- [32]. NHK, <https://www.nhk.or.jp/archives/document/> (15 September 2021 retrieved)
- [33]. Yomidasu Rekishikan, <https://database.yomiuri.co.jp/rekishikan/> (8 September 2021 retrieved).
- [34]. Kikuzou, <http://database.asahi.com/library2/main/top.php> (10 September 2021 retrieved).
- [35]. Maisaku, <https://dbs.g-search.or.jp/WMAI/PCU> (9 September 2021 retrieved).
- [36]. The Asahi, *SNS infected patients supporting with each other*, 7 March 2021 (in Japanese).
- [37]. Google Trends, <http://www.google.com/trends> (10 July 2021 retrieved).
- [38]. Ginsberg, J., M.H. Mohebbi, R. Patel, et al., Detecting influenza epidemics using search engine query data, *Nature* 457 (2009) 1012-1014.
- [39]. Tausczik, Y., K. Faasse, J.W. Pennebaker, et al., Public anxiety and information seeking following the H1N1 outbreak; Blogs, newspaper articles and Wikipedia visits, *Health Communication* 27 (2012) 179-185.
- [40]. Lazer, D., R. Kennedy, G. King et al., The parable of Google flu: traps in big data analysis, *Science* 343 (2014) 1203-1205.
- [41]. Nghiem, L.T.P., S. Papworth, F.K.S. Lim, Analysis of the capacity of Google Trends to measure interest in conservation topics and the role of online news, *PLoS ONE* 11(3) (2016) e0152802.
- [42]. Qin, J. and T-Q. Peng, Googling environmental issues: Web search queries as a measurement of public attention on environmental issues, *Internet Research* 26 (2016) 57-73.
- [43]. Tori, New-type Corona and Tweet sentiments ~ studied whether people were really off their guard during three straight holidays, <https://note.com/torix/n/nf2c50ccb3e51>, (12 July 2021 retrieved, in Japanese).
- [44]. Crocamo, C., M. Viviani, L. Famiglini, et al., Surveilling COVID-19 emotional contagion on Twitter, *European Psychiatry* 2021 (to be published).
- [45]. The Mainichi, An editorial : Internal countermeasures against the new-type pneumonia ; for the information release to answer the public anxiety, (30 January 2020) (in Japanese).
- [46]. The Mainichi, Enthusiastic essay : infection called panic, (4 February 2020) (in Japanese).
- [47]. The Mainichi, Kyoudou Tuushin public opinion survey: new-type pneumonia “worry about it” 82%, (17 February 2020) (in Japanese).
- [48]. The Nihon Keizai, A true culprit is the “extermination of demagogie” : rumor’s walk by itself though it is denied, (6 April 2020) (in Japanese).

- [49]. Tori, "Can the death of one person awake several-hundreds million people?"~ the influence of the death of Shimura Ken on the emotion of people, <https://note.com/torix/n/n55eb66150f41>, (12 July 2021 retrieved) (in Japanese).
- [50]. The Mainichi, The head office public opinion survey : feel anxiety for the infection 81%, (19 July 2020) (in Japanese).
- [51]. The Yomiuri, Facing the corona "insufficiency of information by the Premier" / "self-restraint of family visit" 76%, "anxiety for becoming serious illness" 73%, (10 August 2021) (in Japanese).
- [52]. The Asahi (evening paper, Tokyo), Neon street having been tired: "strained by the declaration one year ago, but this time...", "thinking of no use to bear it anyway", (20 April 2021) (in Japanese).
- [53]. The Asahi (evening paper, Tokyo), Third-times state of emergency "tired", "accustomed": how is your strained degree ?, (20 May 2021) (in Japanese).
- [54]. NHK, <https://www3.nhk.or.jp/news/special/coronavirus/outflow-data>, (8 Sept.2021 retrieved).
- [55]. The Mainichi, The head office public opinion survey: Vaccination not favorable 56%, (19 July 2021) (in Japanese).