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Paper:

How Users of a Smartphone Weather Application Are Influenced by Animated Announcements Conveying Rainfall Intensity and Electronic Gifts Promoting Rain Evacuation

Hiroko Nakajima[*1,†], **Kan Shimazaki**[*2], **Yang Ishigaki**[*3], **Akiko Miyajima**[*1], **Akira Kuriyama**[*4], **Koyuru Iwanami**[*1], **and Yasue Mitsukura**[*5]

[*1] Innovation Center for Meteorological Disaster Mitigation, National Research Institute for Earth Science and Disaster Resilience (NIED)
3-1 Tennodai, Tsukuba, Ibaraki 305-0006, Japan
[†] Correspoinding author, E-mail: h-nakajima@bosai.go.jp
[*2] Institute of Innovation for Future Society, Nagoya University, Aichi, Japan
[*3] Yaguchi Electric Corporation, Miyagi, Japan
[*4] RC Solution Co., Tokyo, Japan
[*5] Department of System Design Engineering, Keio University, Kanagawa, Japan

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In this study, we assumed that animated announcements that conveyed rainfall intensity of localized heavy rain and the distribution of electronic gifts to encourage rain evacuation would promote evacuation actions. If evacuation actions could be promoted through these methods, then the transmission of weather information could be improved. Therefore, we modified the features of a weather information application for smartphones, which was already widely used, and conducted a demonstrative experiment with application users who agreed to participate in order to check the validity. We analyzed users' behaviors by transmitting information regarding the predicted start time of rain and recording the Global Positioning System coordinates of the users' smartphones. In addition, a questionnaire survey was administered to the users after the experiment to collect data on their conception of rainfall intensity. The participants were also interviewed. The results of the experiment showed a significant difference in user conception of rainfall intensity depending on whether they had viewed the animation. However, a behavior analysis based on location data showed no statistical bias in the relationship between the animation and rain evacuation behavior.

Keywords: prediction information, weather application, rainfall intensity, reward, behavioral intention

1. Introduction

The number of localized heavy rain has been increasing in recent years [1]. In most cases, localized heavy rain is a short, severe, local rain generated by suddenly developing cumulonimbus clouds This rain causes severe rainfall amounting to tens of millimeters and lightning, in a short period of time within a small area, affecting quality of life (related to, for example, commuting, attending school, sports, outdoor work, and outdoor recreational activities). Localized heavy rain sometimes cause flood disasters, including drowning accidents or flood damage (e.g., the flood in the Toga River in Kobe City in 2008 and overflow of the Shakujii River in 2010). More research is needed to prevent and mitigate these disasters.

Improvement of meteorological observation technology increases the accuracy and precision of weather forecasts [2, 3] and of the prediction of the rain start time and rainfall intensity. When short-term severe rainfall is forecasted, the involved authorities attempt to provide ordinary citizens with prediction information to help them take appropriate measures. Because short-term severe rainfall have a small temporal and spatial scale, evacuation advisories cannot always be released before the occurrence of a disaster, and people are often required to make decisions and take action without official direction [4]. According to surveys conducted in 2017 by the Ministry of Internal Affairs and Communications and the Japan Meteorological Agency, the percentage of people who have smartphones in Japan and use applications to obtain weather information has been increasing [5, 6], and currently, there are many weather or disaster prevention smartphone applications that release prediction information on short-term severe rainfall [7]. The applications provide this information through push-type notifications. If users of these weather and disaster prevention applications can use the prediction information effectively, they will be able to take appropriate measures against localized short-term severe rainfall, which can occur at any time in any place. One previous study on the transportation system showed that drivers could avoid heavy rain if provided with area information on heavy rain through a car navigation device [8].

However, there have been cases where receiving information that localized short-term severe rainfall was approaching did not facilitate evacuation of the affected area. For example, in 2017, the Tama River Firework Festival was canceled because of predictions of localized heavy rain, but some visitors did not evacuate and were soaked by rain or injured by a lightning strike [9]. In West Japan's heavy rain of 2018, only a small percentage of people in the 17 municipalities of the municipalities in 3 prefectures affected by the rain who received an evacuation order actually evacuated [10, 11]. It is obviously important to clarify the factors that affect people's decision-making, and there are many studies on how to receive information in flood disasters and on risk recognition with the aim of clarifying the important factors [12–14]. Some studies have shown that citizens with a strong interest in rainfall information tend to take evacuation actions [15], and that it was difficult for citizens to understand risks of disasters from information presented in a factual manner, including precipitation [16]. One cannot deny that interest in rainfall information and understanding of the importance of the information affect people's behavior. It is important for those who transmit information and those who receive the information to share the same understanding of the importance of weather prediction information in order to promote citizens' voluntary decision and action.

General prediction information is given in terms of rainfall intensity (hourly precipitation which presents instantaneous rainfall intensity) and amount of precipitation (amount of rain in a fixed period of time). However, ordinary citizens are not used to quantitative evaluation of rainfall intensity or precipitation and may not be able to understand the importance of the prediction when it is expressed in this manner. Moreover, the information receivers may not know that rainfall intensity and amount of precipitation are different concepts. Expressions such as "heavy rain" or "torrential rain" are frequently used, however, the information transmitters and the information receivers may not share the same definitions of these terms. Shimazaki et al. [17] showed that information receivers could not accurately conceive of rainfall intensity only be receiving information with numerical values and qualitative expressions. Therefore, we consider it necessary to provide not only numerical information but also other types of information.

In dual process theory, a theory of cognitive psychology, information processing consists of two systems: system 1 and system 2. System 1 involves unintentional, intuitive, automatic, and fast processing, and system 2 involves intentional, logical, sequential, and slow processing. The two systems complement each other; however, system 1 dominates in the processing of information and is more influential in decision-making [18, 19]. One study [20] supported this theory by showing that information that could help people imagine personal damage was more effective than numerical information because the former could evoke emotions from the receiver. Therefore, under the assumption that intuitive information is more influential than accurate numerical information to general citizens who receive the information, we propose an animation with which the information receivers can have an accurate conception of rainfall intensity and recognize the seriousness more intuitively than with numerical expression or word expression (Proposal A).

The more lead time between the rainfall forecast and the start of rain, the more time people have for making decisions and taking action. However, there is more uncertainty involved for localized heavy rain. Therefore, when the forecast is wrong, the reliability of the information is reduced and people may not evacuate even when a similar event occurs, which places them at great risk for experiencing a disaster [16]. A system needs to be established in which people use prediction information effectively, evacuate from sudden heavy rain voluntarily, and do not suppress evacuation action even if the prediction has failed repeatedly. Operant conditioning [21] is a process in which reinforcement of a certain action or reaction becomes associated with that action or reaction and changes its frequency. This reinforcement is either positive, such as a reward, or negative, such as an expression of hatred. With the former the frequency of the action or reaction increases (positive reinforcement) and with the latter the frequency of the action or reaction decreases (positive punishment). In the field of meteorology and disaster prevention, there have been no studies on the use of reward as positive reinforcement of evacuation behaviors. Unlike rainfall, reward can be controlled by those who give the reward, and hence if reward is given every time, suppression of evacuation behaviors (negative punishment) due to failure of rainfall forecast could be prevented. Evacuation behavior based on prediction information is "negative reinforcement." In the present study, we assume that giving positive reinforcement as well promotes evacuation behavior. Therefore, we propose that, when heavy rain is predicted, an electronic gift that can be used at nearby stores given as a reward (positive reinforce) will promote evacuation behavior (Proposal B).

In order to acquire knowledge useful for improving future meteorological forecast information transmission, the present study aimed to clarify the following influences: (1) the influence on the information receiver's conception and behavior of animation that presented information on rainfall intensity (Proposal A) and (2) the influence on the information receiver's behavior of an electronic gift that was used as incentive for rain evacuation (Proposal B). We conducted a demonstrative experiment of a rainfall prediction application that provided rainfall forecast using animation conveying rainfall intensity, and distributed electronic gift tickets that could immediately be used at nearby stores. Then we analyzed how those who had received the information changed their behaviors on the basis of Global Positioning System (GPS) coordinates data from their smartphones, on which the application was installed. In addition, a questionnaire survey was conducted to collect data on the experiment participants' subjective evaluation of rainfall intensity that they acquired from the animation, and a group interview was conducted with participants who had agreed to be interviewed.

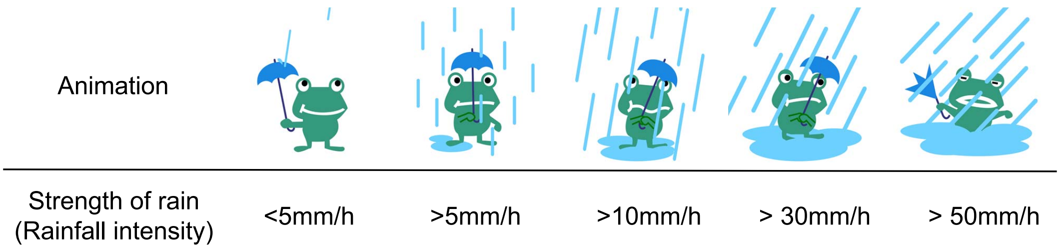

Fig. 1. Animation with different expressions depending on rainfall intensity (Proposal A).

2. Methods

2.1. Rainfall Forecast Application

For the experiment, we used a rainfall prediction application called Amefuru Call ("rainfall call") [22] developed and managed for smartphones and tablets by RC Solution Co. (Tokyo, Japan). The application sends push notification of the predicted time and intensity of rain 30 minutes before the predicted rain start time to the smartphone or tablet to which the application is installed. Rainfall intensity is presented in one of the following five grades: weak rain (5 mm/h or lower), regular rain (5 mm/h or higher), strong rain (10 mm/h or higher), heavy rain (30 mm/h or higher), and severe rain (50 mm/h or higher). In the experiment, rainfall intensity was determined by converting forecasted 10-minute precipitation to hourly precipitation. At the start of the experiment, there were 1.1 million downloads (including 0.6 million downloads of the iOS version of the application).

2.2. Experiment Participants

The experiment participants were users of Amefuru Call who agreed to join the experiment during the experiment period from August 6, 2018 through October 31, 2018. When the application users updated or downloaded the application, the aim of the experiment was presented to them and the experiment was conducted only with those who consented to participate.

After the experiment, the participants were encouraged to answer a questionnaire survey of which most of the questions were on their conception of rainfall intensity. The questionnaire items were on the presence/absence of animation notification, conception of rain intensity, success/failure to receive an electronic gift ticket, and basic demographic information (sex, age, occupation). For each item on conception of rainfall intensity, there were four options: "could have no image," "could have no concrete image," "could have a vague image" and "could have a concrete image." Furthermore, a group interview was conducted with those who agreed to participate, on their perceptions regarding participation in the study and reasons for their behaviors.

2.3. Proposals of Animated Notification and Electronic Gift Distribution Methods

The animation that we made to convey rainfall intensity was a frog character used in the Amefuru Call application. We used a different facial expression and motion depending on the forecasted rainfall intensity. The animation was created through discussion with a weather forecaster, an expert in usability, and a designer, in order to correctly convey rainfall intensity. The number and orientation of lines (representing rain), presence of a puddle and puddle size, and facial expression of the frog were determined based on rainfall intensity (**Fig. 1**). The animation was shown to half of the experiment participants (who had been randomly selected), and ordinary word-based notifications were sent to the other half.

As an incentive to promote rain evacuation, a function to transmit an electronic gift was incorporated into the modification of the application (Proposal B). Following a push notification of strong rain (10 mm/h or higher) or heavier, an electronic gift worth 500 yen was sent to a user with the probability of half if the user's terminal device was located within the radius of 500 m from a target chain coffee shop or chain ice cream shop.

The GPS coordinates data of a terminal device was recorded for 60 minutes from the start of the notification of the rainfall prediction information. If the device could display a notification text above the status bar when it received the notification, recording of the GPS coordinates data began when the user open the application by tapping the notification text. If the device could display the dialogue box at the same time as the notification, recording of the GPS coordinates data began when the user closed the dialogue box. In consideration of the limitations related to the specifications of the operating system and for power consumption, the GPS coordinates were recorded for Android with the interval of 5 minutes and recorded for iOS when the terminal device moved. Because the electronic gift was for users who could walk to a target store within 30 minutes from the notification, we distributed the gift tickets to users in Tokyo and the surrounding area where there were many target stores.

The precise prediction information based on an advanced weather radar and rainfall nowcast method was used [23–25]. It has been reported that the prediction precision of this method is more accurate than that of the Meteorological Agency's high-resolution precipitation nowcast for both cases where Automated Meteorological Data Acquisition System (AMeDAS) observation values are used as true values and cases where XRAIN observation values from the Ministry of Land, Infrastructure, Transport and Tourism are used as true values [25]. The area covered was within a radius of 50 km from Saitama University, and GPS coordinates data were not acquired from users located outside the covered area. The animation was sent to all users inside and outside the covered area, and electronic gifts were sent to users inside the area.

3. Results

A total of 24,330 users agreed to participate in the demonstrative experiment, and a total of 2,066 experiment participants took the questionnaire survey after the experiment was completed. With regard to the level of rainfall during the experiment, frequency of 10-minute precipitation (AMeDAS observation) during the experiment period in the area within the radius of 50 km from Saitama University is shown in **Fig. 2**, and maximum daily rainfall intensity at AMeDAS observation point (Tokyo) nearest to Minato Ward [26], which has the largest daytime population, is shown in **Fig. 3**.

First, we analyzed the result of the questionnaire survey to study the influence of the animation on user conception of rainfall intensity. **Table 1** is a frequency distribution table for the question on user conception of rainfall intensity with or without the animation. We performed a chi-square test under a null hypothesis that the bias in the number of answers given by the experiment participants to the question on conception of rainfall intensity did not change. As a result, the bias of the frequency was significant (chi-square value = 201.15, degrees of freedom = 3, significant probability $< .001$), and more users in the group that saw the animation answered that they could grasp the level of rain intensity than those in the group that did not see the animation.

Next, we analyzed user behavior based on GPS coordinates data. If an experiment participant had been outdoors (i.e., not in a building, car, or train) when he or she received the notification and entered a building within 60 minutes after the notification, this behavior was defined as rain evacuation, whether it actually started raining or not. This determination was made based on GPS coordinates data and their accuracy, and the last acquisition of the data was made 60 minutes after the notification. The final percentage of users who "evacuated from rain" was 70.5%. Next, we investigated whether the evacuations were successful. If a user who had been outdoors at the time of notification could enter a building before the actual observation data of precipitation first reached 1 mm or higher, his or her behavior was considered a "successful evacuation." If he or she remained outdoors even when it had begun to rain, the behavior was considered a "failed evacuation." Based on the information from the Meteorological Agency's website [27] and discussions with the weather forecaster and expert on meteorological prediction, "start of rain" was defined as when people would begin using their umbrellas (i.e., when the rainfall intensity reached 1 mm/h).

Of all the participants who saw the animation, 174 had successful evacuations, and 123 had failed to evacuate. Of all the participants who did not see the animation, 164 participants had successful evacuations, and 105 had failed to evacuate. **Fig. 4** shows the relationship between the presentation of the animation expressing the rainfall in-

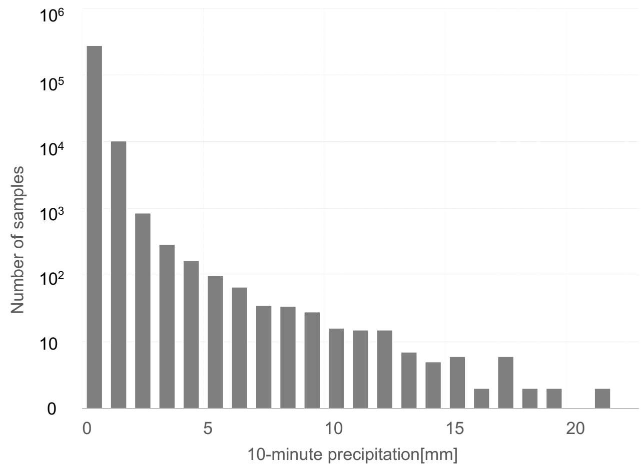

Fig. 2. Histogram of 10-minute precipitation (created from AMeDAS observation data).

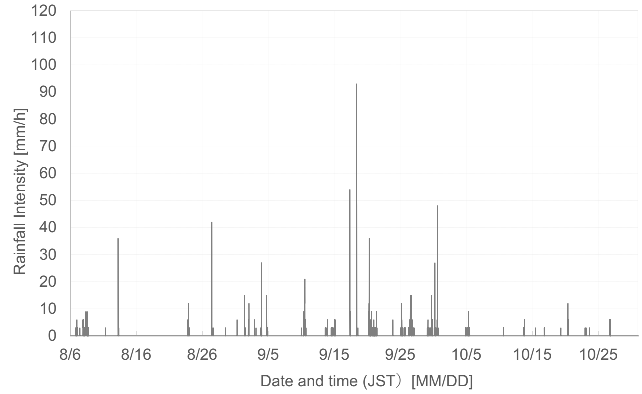

Fig. 3. Maximum daily rainfall intensity in Tokyo (created from AMeDAS observation data).

Table 1. Animation presentation and conception of rainfall intensity.

Image of rain intensity	Animation	
	Not shown	Shown
Could have no image	83	19
Could have no concrete image	136	169
Could have a vague image	417	971
Could have a concrete image	96	473
Total	732	1632

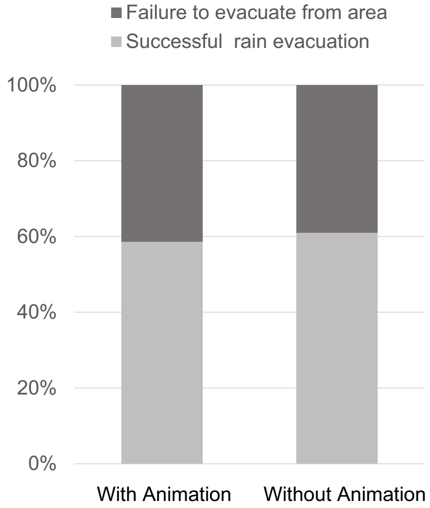

Fig. 4. Relationship between presentation of animation and success of rain evacuation, derived from GPS coordinates data.

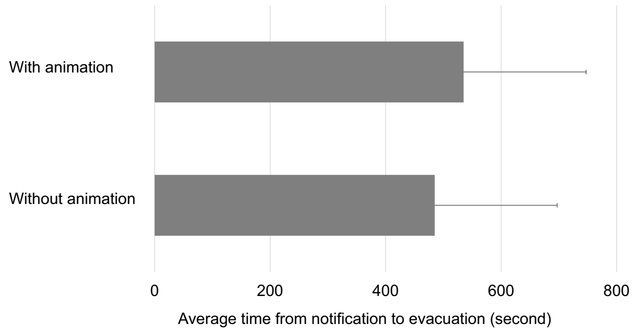

Fig. 5. Comparison of time from notification with animation to when the users began evacuating (with error bar showing the standard deviation).

tensity and the success rate of the evacuations as determined by the GPS coordinates data. Under a null hypothesis that there would be no bias in the success/failure of rain evacuations depending of the presence or absence of the animation, we performed a chi-square test. As a result, we found no significant statistical difference in the success rate of rain evacuations depending on the presence/absence of the animation (chi-square value $= 0.24$, degrees of freedom $= 1$, significant probability $= 0.623$).

Of all the experiment participants whose GPS coordinates data were collected, the number of participants who saw the animation was 297, and the number of participants who did not see the animation was 269. We performed a t-test for the average time between notification to the start of evacuation with or without the animation. First, we conducted an F-test to verify homoscedasticity. Because the result indicated that we could not assume homoscedasticity (F value $= 1.639$, degrees of freedom of numerator $= 268$, degrees of freedom of denominator $= 296$, significant probability $< .001$), we applied Welch's t test. However, there was no statistical difference between the two groups (**Fig. 5**; t value $= -0.76$, degrees of freedom $= 506.1$, significant probability $= 0.442$).

In the demonstrative experiment, the number of participants who received the electronic gift was 57 in total (30 for ice cream and 27 for coffee). The behavior data could be acquired from GPS for 28 participants among them. Because the number of participants who received the electronic gift was not high enough to make a statistical analysis of the behavior, we analyzed the trace of the movement of these individuals to determine whether they went to one of the target stores. Among the 28 participants whose behavior data was acquired, some stayed in a building, car, or train when the notification arrived. The result of the analysis shows that there were eight (28%) who went to a target store.

Major findings from the group interview with 10 participants (7 women and 3 men, aged between 40 to 59 years) were as follows: One experiment participant said that he or she joined the experiment because the frog character was cute. Another participant said that he or she did not even notice the animation. Therefore, the impression of the animation varied from person to person. With regard to the behavior after receiving the notification, some reported that the information effectively aided them in determining what to wear, how to evacuate, where to spend their time, and whether to interrupt their work. Others reported that they would have evacuated if they had been free to do so, but they could not evacuate because of work or being with a friend. In addition, there was an opinion that the electronic gift would be useful in finding a store to which people could evacuate from rain. However, some participants said that they did not want to use the gift ticket by themselves. One participant commented, "A middle-aged man like me is hesitant to go to an ice cream shop alone."

4. Discussion

The results of the questionnaire survey indicated that presenting the rain forecast information as an animation significantly assisted users in gaining a more accurate conception of the intensity of the rainfall. Therefore, the information provision method proposed in the present study was effective in improving participant recognition. However, there was no statistically significant difference in evacuation success rate between those who had viewed the animation and those who had not. Nor was there a statistically significant difference between the two groups in time from notification to evacuation. Also, the information provision method using the animation did not affect the behavior of the experiment participants. This could be because, as indicated by the results of the group interview, the decision to evacuate could be influenced by various factors such as schedule and accompanying persons, and the information provision method used in the study was not effective enough to affect these factors.

The present study aimed to perform a social experiment using an actual application operated by a company. Therefore, it was necessary to modify the system so that the company could continue operating the application during the experiment. Due to this restriction, the range of data that could be acquired was limited, and a transmission log of the time of the rain forecast notification and a distribution log of the precipitation data sent to the users were not obtained. Therefore, we used actual observation data for analysis of success or failure of rain evacuations. As a result, we could not identify the relationship between receiving the animation conveying rainfall intensity and evacuation behaviors. In addition, the conditions for sending the electronic gift were too rigid (as will be discussed below) to send a sufficient number of gifts, and hence we could only perform a qualitative analysis of the influence of reward on rain evacuation. These limitations should be addressed in future demonstrative experiments.

It is difficult to evaluate the use rate of the electronic gift (28%) because of the small sample and lack of comparable experiments under the same conditions. The use rate of a coupon provided to all users by a domestic major communication company, which was usable on a specific day of the week, was about 7% (according to a 2016 study) [28, 29], and the evacuation rate of people to which an evacuation order was placed in the West Japan heavy rain of 2018 was a small percentage in all municipalities [10, 11]. Therefore, the rate of 28% indicates the possibility that the distribution of the electronic gift before rainfall could serve as an effective incentive for evacuation.

The number of the experiment participants who received the electronic gift in the experiment was not high enough to perform a statistical analysis. This was not only because of the system issue but also because of the rule that each user could only receive the gift once. This rule was designed to prevent a user who had a house or office near a target store from getting the gift repeatedly. Furthermore, the GPS coordinates data of some users who received the electronic gift could not be acquired. On the terminal device that displayed the notification text on the status bar when the notification arrived, the GPS coordinates data began to be recorded when the user tapped the notification text and opened the application window. Therefore, the inability to obtain GPS coordinates data for some users might have been because he or she did not tap the screen when receiving the notification. The user most likely did not tap the screen because he or she did not notice the notification, considered the notification information received before tapping the screen to be sufficient, or was in a situation where he or she could not tap the screen. Moreover, there were limitations on the number of users who could receive the notification. This is because the application was for natural phenomena, and only users who happened to be in a place where the rainfall intensity was 10 mm/h or higher at that time received the notification. This means that, even if several tens of thousands of people use the application, only a few people receive information on heavy rain disasters that occur several times a year; hence, transmission means to spread disaster information widely and sufficiently would be necessary.

Future studies should acquire logs of the notification time and notification content, including rainfall intensity. Clarify of the mechanism of people's behavior for different rain intensities is also needed; applications users should be asked about their behavior in order to collect details on the behavior, such as its purpose, which is difficult to assess from behavior data only. By doing this, we will be able to determine whether there is a gap between behavior intention and actual behavior [30, 31], which has been indicated in previous disaster prevention studies. To use an electronic gift as incentive in an experiment, appropriate setting of the distribution conditions and an appropriate guide from the rainfall notification to a screen of the application are necessary to increase the number of people who receive the gift and for statistical analysis of their behavior. However, social implementation of the system has problems such as cost of the electronic gift. Therefore, we need to not only consider who pays for the gifts but also find an incentive or another positive reinforcer that costs nothing but satisfies user achievement motivation and collection demand, taking advantage of the know-how collected from gamification. To provide more effective images, one can use photographs instead of animation. However, it is expected that people would choose the application with the animation depicting a cute frog over video images of a person in the rain. In the present demonstrative experiment, we studied localized heavy rain evacuations; however, it is also necessary to study evacuation to an evacuation site under an evacuation advisory.

5. Conclusions

In the present study, we investigated how animation conveying rainfall intensity affect user conception of rainfall intensity and verified the effect of an electronic gift given as incentive for evacuation before localized heavy rain. These features were added to the push-notification function of a rainfall forecast application for smartphones to analyze the behavior of the experiment participants. A questionnaire survey was conducted to obtain subjective evaluations, and a group interview with some of the participants was also conducted. As a result, the following four points were clarified:

(1) The animation aided the user in gaining a more accurate conception of rainfall intensity.

(2) There was no statistically significant difference in the success rate of the rain evacuation or the time from notification to evacuation between those who had received the animation and those who had not, and whether they had received the animation did not influence the behavior of the participants.

(3) No sufficient data for analysis of the relationship be-

tween the electronic gift and rain evacuation behavior could be obtained.

(4) The interview with the participants indicated that the consciousness and impressions of the animation varied from person to person, and that some of them would not use the electronic gift because of the gift content, their schedule, or being with a friend.

Acknowledgements

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Name:
Hiroko Nakajima

Affiliation:
Collaborative Partnership Promotion Manager, Innovation Center for Meteorological Disaster Mitigation, National Research Institute for Earth Science and Disaster Resilience (NIED)

Address:
3-1 Tennodai, Tsukuba, Ibaraki 305-0006, Japan

Brief Career:
2006- Assistant Fellow, Center for Environmental Risk Research, National Institute for Environmental Studies
2009- The Science and Technology Promotion Foundation of Ibaraki
2011- Japan Science and Technology Agency
2015- NIED

Selected Publications:
• Y. Ishigaki, H. Nakajima, and K. Shimazaki, "Observations and notification technology of sudden rainfall, Smart Water Sensing for Human Life Support," Research Committee on Smart Water Sensing for Human Life Support (Ed.), "Smart Water Sensing for Human Life Support," CMC Publishing Co., Ltd., pp.152-164, 2019.

Academic Societies & Scientific Organizations:
• Japan Society for Intellectual Production

Name:
Kan Shimazaki

Affiliation:
Institute of Innovation for Future Society, Nagoya University

Address:
NIC-613, Furo-cho, Chikusa-ku, Nagoya, Aichi, Japan

Brief Career:
2008- Research Associate, Faculty of Human Sciences, Waseda University
2011- Assistant Professor, Faculty of Human Sciences, Waseda University
2015- Special Researcher, National Research Institute for Earth Science and Disaster Resilience (NIED) (NIED)
2019- Associate Professor, Nagoya University

Selected Publications:
• K. Shimazaki, "A Study of Anxiety," Kobunsha, 2016.

Academic Societies & Scientific Organizations:
• Japanese Association of Traffic Psychology (JATP)
• Japanese Psychological Association (JPA)
• Japan Ergonomics Society (JES)

Name:
Yang Ishigaki

Affiliation:
The University of Electro-Communications

Address:
1-5-1 Chofugaoka, Chofu, Tokyo 182-8585, Japan

Brief Career:
2002-2012 Intelligent Systems Laboratory, SECOM Co., Ltd.
2012- Director, CTO, Yaguchi Electric Corporation
2019- Associate Professor (Specially Appointed), The University of Electro-Communications

Selected Publications:
• Y. Ishigaki, Y. Matsumoto, R. Ichimiya, and K. Tanaka, "Development of Mobile Radiation Monitoring System Utilizing Smartphone and Its Field Tests in Fukushima," IEEE Sensors J., Vol.13, No.10, pp.3511-3519, 2013.
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Name:
Akiko Miyajima

Affiliation:
Innovation Center for Meteorological Disaster Mitigation, National Research Institute for Earth Science and Disaster Resilience (NIED)

Address:
3-1 Tennodai, Tsukuba, Ibaraki 305-0006, Japan

Brief Career:
2007 Get national license of Weather Forecaster
2012- Smart-life Solutions Department, NTT docomo
2016- Innovation Center for Meteorological Disaster Mitigation, NIED

Academic Societies & Scientific Organizations:
• Meteorological Society of Japan (MSJ)
• Certified and Accredited Meteorologists of Japan (CAMJ)

Name:
Akira Kuriyama

Affiliation:
CEO, RC Solution Co.

Address:
Souei Building 3F, 8-14-21 Nishi-Shinjuku, Shinjuku, Tokyo 160-0023, Japan

Brief Career:
1988- System Engineer, Software Industrial Co., Ltd
1995- System Engineer, InterAct Co., Ltd.
2002- CEO, RC Solution Co.

Selected Publications:
• R. Aibiki, N. Yoshizawa, K. Yamaguchi, T. Shimomura, T. Hikawa, Y. Taki, M. Yamazoe, and A. Kuriyama, "Method of Providing Disaster Information to Foreign Tourists Visiting Japan," Japan Society for Safety Engineering, Vol.55, No.3, 2016.

Academic Societies & Scientific Organizations:
• Tokyo Association of Small And Medium-Sized Enterprises

Name:
Koyuru Iwanami

Affiliation:
Principal Chief Researcher, Storm, Flood and Landslide Research Division, National Research Institute for Earth Science and Disaster Resilience (NIED)

Address:
3-1 Tennodai, Tsukuba, Ibaraki 305-0006, Japan

Brief Career:
1991 Joined National Research Institute for Earth Science and Disaster Prevention (NIED)
2002-2003 Visiting Scientist, CETP/CNRS, France
2013-2016 Director, Storm, Flood and Landslide Research Unit, NIED
2018- Director-General, Research Center for National Disaster Resilience, NIED

Selected Publications:
• K. Iwanami, K. Hirano, and S. Shimizu,"Statistical Validation of the Predicted Amount and Start Time of Heavy Rainfall in 2015 Based on the VIL Nowcast Method," J. Disaster Res., Vol.14, pp. 248-259, 2019.
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Academic Societies & Scientific Organizations:
• American Meteorological Society (AMS)
• Meteorological Society of Japan (MSJ)
• Japanese Society of Snow and Ice (JSSI)
• Japan Geoscience Union (JpGU)

Name:
Yasue Mitsukura

Affiliation:
Professor, Department of System Design Engineering, Keio University
Chief Technical Officer, Dentsu ScienceJam Inc.

Address:
3-14-1 Hiyoshi, Kohoku, Yokohama, Kanagawa 223-8522, Japan

Brief Career:
1999- Research Associate, Tokushima University
2001- Lecturer, Okayama University
2005- Associate Professor, Tokyo University of Agriculture and Technology
2011- Associate Professor, Keio University
2018- Professor, Keio University

Selected Publications:
• Y. Mitsukura, K. Fukunaga, M. Yasui, and M. Mimura, "Sleep Stage Detection Using only Heart Rate," Health Informatics J., doi: 10.1177/1460458219827349, 2019.
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Academic Societies & Scientific Organizations:
• Institute of Electrical and Electronics Engineers (IEEE)
• Society of Instrument and Control Engineers (SICE)
• Research Institute of Signal Processing (RISP)
• Institute of Electrical Engineers of Japan (IEE)
• Japan Society for Higher Brain Dysfunction (HBFR)