A Study of a Sense of Crisis from Auditory Warning Signals

Mie Nakatani, Daisuke Suzuki, Nobuchika Sakata, and Shogo Nishida, *Non-Member, IAENG*

***Abstract*— This paper presents two experiments to evaluate the impression of auditory warning signals. In recent years, there are many natural disasters. The evacuation procedure is one of the pressing problems. Some audible alerts are entrenched in our daily life, such as police siren, ambulance siren, emergency bell, fire alarm and so on. Most people, however, don't escape by hearing the alert. People have a cry-wolf syndrome. Some researches have been studied for people to take appropriate action. One is going in the direction of education or training for people. Another is going in the direction of improved evacuation call. We have studied about auditory signals to assist the design of the warning systems. Our final goal is to design the auditory warning signals which make people maintain a sense of urgency. We assume that the monotonous alarms become familiar to people. In this paper, the dynamic change due to a degree of danger is focused. First, the reference parameters are settled by the reaction time experiment. Then the effect of dynamically change in parameters is subjectively evaluated.**

***Index Terms*— auditory warning signal, response time, pitch, frequency, waveform, psychological experiment.**

I. Introduction

Disaster prevention and mitigation are the high-priority issues in Japan where there are many natural disasters. Immediate evacuation is required to reduce human damage. However the rate of evacuation of residents is very low. The rate of evacuation is no more than 50%, though it varies from disaster to disaster. The reasons are reported as following[1]:

- Cry-wolf syndrome. Disaster doesn't sometimes happen despite a warning notice. After the prediction was off two or three times in a row, people don't believe the warning.

- Bias of underestimation. People have a tendency to interpret information conveniently for them. They are apt to think them will not be damaged.

- Lack of knowledge about disaster information and natural phenomenon.

Additionally Katada's survey[2] shows other reasons. Some people couldn't evacuate because they themselves or their family had some physical constraints or they didn't know the procedures or roots of evacuation. Other people didn't evacuate because they couldn't leave their household goods and tools of their livelihood.

It is not easy to lead people who do not want to evacuate. There are psychological approach and engineered approach to evacuation issues. From the perspective of social psychology, researchers have developed the education and training method for disaster prevention and mitigation, and supported the development of a community network for mutual helpfulness. From the perspective of engineering, easily comprehensible warning notices, the emergency exit sign in media mix and the accurate and pinpoint hazard assessment have been studied.

In this paper, the purpose is the guideline of the interface design to convey a crisis mentality from the perspective of interface engineering. Referring to the previous records, people rarely get panics. On the contrary, most people get used to the warning alert. We have started experiments to develop the warning calls which give people moderate nervousness. Here we report two experiments on parameters of auditory warning signal.

II. Related Works

In this chapter, related studies about auditory warning signal are reviewed from a standpoint of ergonomics or interface engineering.

According Kuwano[3], a warning signal has to meet the following requirements.

1. It has to be easily perceived in any noisy conditions.
2. It has to be easily perceived by every age group, elderly people with hearing loss.
3. It has to be easily recognized as a warning sings even after being perceived.
4. It has to have universality transcending national boundaries. In other words, it has to be recognized as a warning sings in any countries or any language.

First, auditory signals have to be recognized without paying any attention to them even if in noisy surroundings. There are many researches about detectability of siren[4-6]. Guo[7] made experiments about sirens easily heard by hard-of-hearing person and about distance of hearing sirens. Also, basic siren used for industrial product are standardized[8-9].

Second, auditory signals have to make everyone perceive instinctively that something dangerous happens. Appreciation of signal's meaning has two problems, culture-specific perception gap and difficulty to distinguish a critical alert from other various signals. There are many

Manuscript received July18, 2009. This work was supported partially by the SECOM science and technology foundation. This research was partially supported by the Ministry of Education, Science, Sports and Culture, Grant-in-Aid for Scientific Research (C), 19510171, 2007.

M. Nakatani is with the Center for the Study of Communication Design, Osaka University, Toyonaka, Osaka 560-0043 Japan (fax: +81-6-4865-0121; e-mail: mie@ cscd.osaka-u.ac.jp).

D. Suzuki, N. Sakata and S. Nishida are with Graduate School of Engineering Science, Osaka University, Toyonaka, Osaka 560-8531Japan (e-mail: {suzuki, sakata, nishida}@ sys.es.osaka-u.ac.jp).

auditory signals in everyday situations. Various annunciation signals come from appliances in one's house, announcement in the station or vehicle, vending machines or door way in the town and so on. About cross-cultural comparison, Kuwano[10] researched subjective impression of auditory signals between Japan, Germany and America. Some sounds roused the opposite evaluation in different countries. It was suggested that the signal whose frequency shifted and the frequency swept from low to high over a wide range gave the impression of dangerousness and that the impression became more dangerous as the off-time became shorter.

About various signals in daily life, Yamauchi[11] studied the evaluation axis of sound image from various daily signals. It showed that people's signals images ware divided into two directions. One was "warning or notice," the other was "calling or starting". For periodic modulated sound, when the modulating frequency of the signal was from 1.25Hz-5.0Hz, people recognized it as a warning or notice. When the modulating frequency of the signal was from 10.0Hz-50.0Hz, people recognized it as a calling or starting. Particular signals, for workplace signals like heavy equipments, a cockpit or medical devices, are prescribed in respective specifications like ISO or JIS.

As well as above-mentioned studies, there are many researches about images of signals[12-13]. According to Kuwano[10], the higher the frequency of signal is, the more danger people feel it. And the shorter the silence at intervals during the sweep sound is, the more danger people feel it.

III. Concept and Methodology

This paper deals with images of warning signals to control critical feelings. People will soon get used even the appropriate signals as mentioned in the chapter 1. So we aim to change the signal impression depending on the situations. For an example, a fire alarm apparatus is the typical signal which even if people hear, anyone doesn't evacuate. But people will feel different than usual and try to see what happened if the sound changes according to the situation at the time. The transmutative signal will make people become more and more uncomfortable. Though previous works suggest the appropriate parameters of warning signals, they don't mention the psychological change depending on the transmutative signals. We examine that changing the parameter of signals will control the dangerous impression.

At the first experiment, we determine the basis parameters by measuring the response time. Most studies use the Semantic Differential method to evaluate subjective images. However we require the quantitative data, not the qualitative evaluation, to determine the basis parameter. So we try to adopt the new evaluation method. Subjects are asked to push a button as soon as they decide to evacuate by hearing a sound. If the signal gives them the urge to run away, the response time will become short. The relation with the parameter of sound and the response time can be quantitatively analyzed.

At the next experiment, the intergraded signals are evaluated with subjective impression.

IV. Experiments

A. Experiment I

This experiment's goal is to make clear the relation between the parameter of signal and the response time to push the evacuate button.

Material

This research targets the sweep sound as a warning signal. We prepare the 80 signals by the combination of the four parameters as the following. Each signal is five seconds.

- Wave pattern: sine-wave, square-wave
- Pitch: high, low [sine-wave: -7dB, -13dB,
  square-wave: -10dB, -16dB]
- Modulation period: 1Hz, 2Hz, 4Hz, 8Hz
- Frequency: 160Hz-320Hz, 320Hz-640Hz,
  640Hz-1280Hz, 1280Hz-2560Hz,
  2560Hz-5120Hz

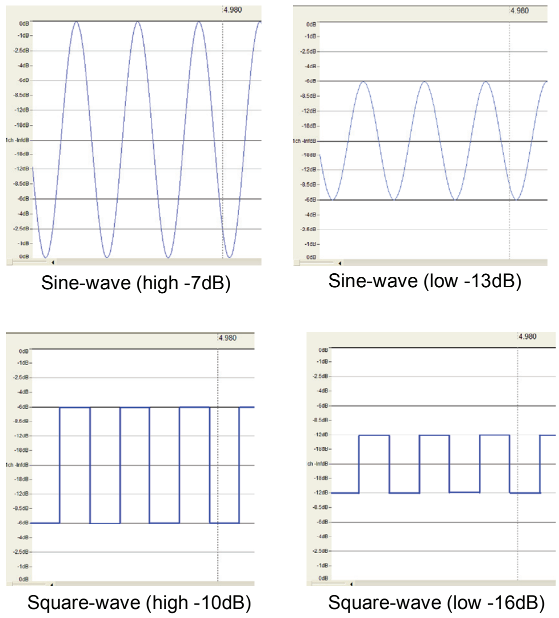

Figure 1. The sine-wave and the square-wave

Procedure

A note PC and a headset are used for the experiment (Figure 3). These 80 signals are played in random order. Subjects are required to push a button either "Escape" or "Not Escape" as soon as the signal is played. In addition, they are asked to select one among the following five descriptions for every signal(Figure 2).

- This signal has no impact.
- This signal is "the appropriate tension". I can dispassionately evacuate. ("The appropriate tension" sounds odd. It means the tension is moderate. Despite a sense of urgency, people can make judgments unflappably.)
- This signal is too noisy. I can't dispassionately evacuate.
- This signal is rather a departure bell than a warning.
- This signal is neither a warning nor a departure bell.

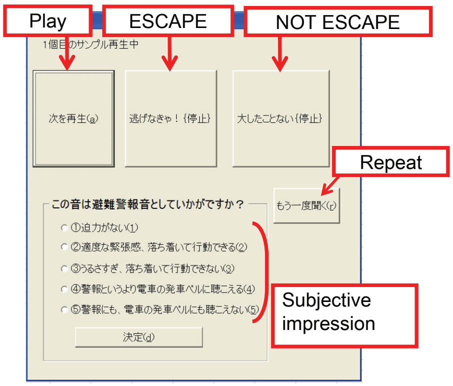

Figure 2. The display of the first experiment

Figure 3. Scenes of the first experiment

Subjects are 56 who are 5 females and 5 males in 10s, 3 females and 13 males in their 20s, 5 females and 5 males in 30s, 5 females and 5 males in 40s and 5 females and 5 males in 50s.

Result

Average time to evaluate 80 signals was about ten minutes per one subject. The upper threshold of the response time is set to nine seconds. When the response time is over nine minutes, or “Not escape” or “Repeat” button is chosen, the response time is regarded as ten minutes for convenience. Table 1 shows the median value of the response time(second). This time, statistical significant differences are not calculated.

First, the entire spectrum of the data is reported.

About the waveform, the subjects respond more quickly to the square-wave than the sine-wave.

Focusing on Pitch, high pitch has a tendency to have shorter response time.

Focusing on modulation period, they are slow to response to the signals of 1Hz.

Focusing on frequency, the response time of the signals from 160Hz to 640Hz of sine-wave are over ten seconds. About the signals of 640Hz-2560Hz in both waves, they respond quickly. About the signals of 2560Hz-5120Hz, there is discrimination based on age (It is described more about these later, Table 2).

TABLE 1. THE RESULT OF THE RESPONSE TIME

The response time less than two seconds
The response time less than three seconds
Most subjects subjectively evaluate it as “the appropriate tension”.

Sine-wave (high -7dB) (second)

Modulation / Frequency	1	2	4	8
160-320	10	10	10	10
320-640	10	10	10	10
640-1280	10	3.14	2.5	4.92
1280-2560	10	3.3	3.08	2.69
2560-5120	5.69	3.57	3.6	2.12

Sine-wave (low -13dB) (second)

Modulation / Frequency	1	2	4	8
160-320	10	10	10	10
320-640	10	10	10	10
640-1280	10	10	10	10
1280-2560	10	7.75	3.2	4.98
2560-5120	10	5.26	4.03	3.26

Square-wave (high -10dB) (second)

Modulation / Frequency	1	2	4	8
160-320	4.31	2.69	2.73	6.44
320-640	2.68	2.39	2.11	2.29
640-1280	2.58	2.19	1.9	1.79
1280-2560	2.53	2	2.04	1.99
2560-5120	3.92	2.26	2.3	2.29

Square-wave (low -16dB) (second)

Modulation / Frequency	1	2	4	8
160-320	10	10	10	10
320-640	7.32	2.84	2.9	6.24
640-1280	3.62	2.58	2.08	2.86
1280-2560	5.17	2.82	2.46	2.49
2560-5120	10	3.28	2.75	2.92

About subjective impression, the low- frequency signal is evaluated as “no impact”. The high-frequency signal is evaluated as “too noisy”. The signals of 640Hz-2560Hz and 1Hz-2Hz modulation period have a tendency to be evaluated as “the appropriate tension”. There is few discrimination based on age. In Table 1, the bold-lined cells mean the shortest response time and the dotted cells mean the good impression as “the appropriate tension”. The quick response does not necessarily correspond to the good impression.

On the whole, these results don’t show that the higher frequency or modulation period induce the quick response. Too high frequency is only harsh and don’t enhance evacuation. The square-wave signals from 640Hz-2560Hz frequency and 4Hz-8Hz modulation period induce the quick response. The square-wave signals from 640Hz-2560Hz frequency and 1Hz-4Hz modulation period are subjectively evaluated as “the appropriate tension” by most subjects.

Totally, we may use the 640Hz-1260Hz frequency and 2Hz modulation period as the basis parameter for the next experiment.

Secondly, the result according to subject’s properties is reported.

On a gender basis, Table 2 shows that female subjects respond more quickly than male. There is really not much difference among male response time. On the other hand, female respond either quickly or slowly. There is no difference in subjective evaluation.

By age, there is really not much difference from 20’s to 50’s about the response time and subjective evaluation. How ever, the response time by 10’s subjects is very short. Most of cells of Square-wave(high -10dB) in teens are less than two seconds(Table 3). The subjects who are in their twenties or in older respond in about 3 seconds.

On the contrary, the response time of Square-wave(l -16dB) in fifties is long. Other ages(from twenties to forties) respond in about 3~5 seconds.

About subjective evaluation, there is no difference in ages.

TABLE 2. THE COMPARISON AMANG SEXS OF SQUARE-WAVE (HIGH -10DB)

The response time less than two seconds
The response time less than three seconds

Square-wave (high -10dB) on female (second)

Frequency \ Modulation	1	2	4	8
160-320	4.789	2.652	2.715	10
320-640	2.64	2.309	1.904	2.169
640-1280	2.449	1.953	1.778	1.513
1280-2560	2.527	1.748	2.172	1.575
2560-5120	4.072	2.262	2.278	2.121

Square-wave (high -10dB) on male (second)

Frequency \ Modulation	1	2	4	8
160-320	3.712	2.828	2.75	5.834
320-640	3.183	2.578	2.746	2.34
640-1280	2.652	2.371	1.997	1.809
1280-2560	2.543	2.532	1.904	2.091
2560-5120	3.813	2.277	2.418	2.621

TABLE 3. THE COMPARISON AMANG AGES OF SQUARE-WAVE (HIGH -10DB)

Square-wave (high -10dB) in 10’s (second)

Frequency \ Modulation	1	2	4	8
160-320	2.901	2.222	1.708	8.526
320-640	1.918	1.576	1.482	1.77
640-1280	1.888	1.677	1.693	1.498
1280-2560	1.584	1.434	1.295	1.366
2560-5120	1.404	1.35	1.771	4.383

Square-wave (high -10dB) in 50’s (second)

Frequency \ Modulation	1	2	4	8
160-320	4.009	4.735	3.362	10
320-640	3.846	2.512	1.942	2.465
640-1280	3.433	3.416	1.809	1.973
1280-2560	2.332	2.145	2.387	2.222
2560-5120	4.141	3.596	2.356	2.184

TABLE 4. THE COMPARISON AMONG AGES OF SQUARE-WAVE (HIGH -16DB)

Square-wave (low -16dB) in 10’s (second)

Frequency \ Modulation	1	2	4	8
160-320	7.216	3.026	10	10
320-640	2.582	2.145	4.11	10
640-1280	3.268	2.208	1.326	1.747
1280-2560	2.23	3.012	1.459	1.748
2560-5120	2.434	2.067	1.716	1.365

Square-wave (low -16dB) in 50’s (second)

Frequency \ Modulation	1	2	4	8
160-320	10	10	10	10
320-640	10	2.574	2.91	10
640-1280	10	4.189	3.183	3.198
1280-2560	10	2.465	2.169	3.604
2560-5120	10	2.574	3.642	4.321

B. Experiment I

This experiment's goal is to ascertain whether the changing parameter makes subjects feel more in danger.

Material

This time we change three parameters in three steps. From the result of the first experiment, 1280Hz frequency and 2Hz modulation period are set as the middle value of three steps. The parameters are changed as the following. We incrementally change these parameters on both sine-wave and square-wave.

- Pitch: sine-wave: -13dB > -10dB > -7dB
  square-wave: -16dB > -13dB > -10dB
- Modulation period: 1Hz > 2Hz > 4Hz
- Frequency:
  320Hz-640Hz > 640Hz-1280Hz > 1280Hz-2560Hz

The signals are combined by three patterns: one parameter change, two parameters change, three parameters change.

- incremented by one parameter: three signals
- incremented by two parameters at the same time: three signals
- incremented by three parameters at the same time: one signal

These patterns are made on both sine-wave and square-wave, so the total is 14 signals. Each signal is fifteen seconds(the parameters is changed every five seconds).

Procedure

A note PC and a headset are also used for this experiment. The 14 signals are played in random order. Subjects are required to evaluate the degree of urgency by sliding a bar when the signal is played(Figure 4). One signal is composed of three steps. So they have to evaluate three times for one signal. Subjects are sixteen university students and graduate students(13 males and 3 females. Age is from 22 to 25.)

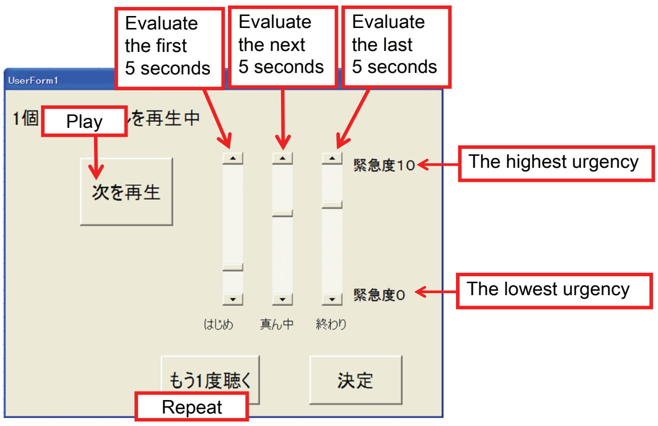

Figure 4. The diplay of the second experiment

Result

Average time to evaluate 14 signals was about five minutes per one subject. The slide evaluation score is ranged from 0 to 10.

This time the evaluation score of the middle parameter is center justified for comparison of all signals(Figure 5). When one parameter is changed, the degree of urgency increases slightly according to the incremented parameter. Among parameters, frequency is an effective parameter to inform the dangerous situation. When two parameters are changed at the same time, the degree of urgency increases more. When three parameters are changed altogether, the degree of urgency considerably increases.

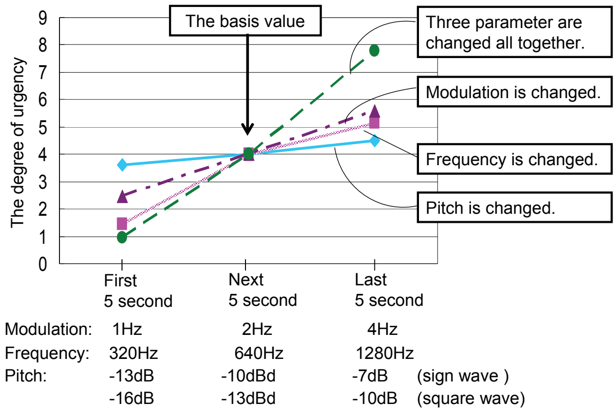

Figure 5. The parts of the result of the the second experiment

C. Discussion

Previous researches say that the higher the frequency of signal is, the more danger people feel it. But the result of the first experiment suggests that the high frequency isn't always better. Although high frequency signals make a strong impression on subjects, they are in danger of making people misjudge. The impression of signals varies among different individuals and cultures. Today cell-phone and ubiquitous computing are in widespread use. Auditory signal is able to be designed according to the situation and individual.

About the evaluation method this time, it is not exactly that the response time is the best way. The quick response time does not correspond to the "appropriate signal" evaluation. But there are some trends in the distribution of the response time. It is said that the response time means the human physiologic reaction to the sense of crisis and it does not necessarily correspond to the subjective impression. This difference between the response time and the subjective impression will be valuable to design the auditory sign in some applications.

The result of the second experiment suggests the possibility to control the impression of the warning signal. By combining the parameters, we will be able to operate the urge to escape. Furthermore the dynamic change of the warning signal will prevent people from getting accustomed to the emergency call and cause a refreshing feeling.

Finally, in these experiments, subjects listen to the signals on each headset. We adopt the headset to control the condition strictly. But nobody hear on a headset in the real situation. And the experiments were done undisturbedly, subjects were not in an intense atmosphere. It is very difficult to make subjects feel real tension in the laboratory because of ethical issues. We have to consider the result under such a condition.

V. Conclusion

Today, disaster prevention and mitigation are the urgent issue. A lot of efforts have been done to minimize damage. To develop the appropriate evacuation calls is one of the important problems, because most people don't escape despite hearing the call. There are some reasons why they don't evacuate. This study focuses on the psychological factor in the evacuation calls. The auditory property of the warning signals has been studied by many researchers. Most of them use the subjective evaluation and don't focus the temporal changes of signals. In this paper, we adopt the measurement of response time to evaluate quantitatively and focus on the temporal change of signals. We think the dynamic change of signals will prevent people from getting accustomed to the emergency call and refresh the feeling of tension. The result of two experiments shows the possibility to control the urgency impression by operating the parameters. As future tasks, we have to make experiments with more subjects and more countries. Our final goal is to construct the guideline of interface design for emergency information system.

References

[1] Honma, M. and Katada, T.: Study on the Relationship between Disaster Advance Information and Resident Evacuation In Tsunami Disaster Prevention, Journal of Disaster Information Studies, Vo.6, 2008, pp.61-72 (in Japanese).

[2] Katada, T., Kuwasawa, N., Kanai, M. and Kodama, M.: Study of Social technology and Reassurance from TSUNAMI Disaster, SOCIOTECHNICA, Vo.2, 2004, pp.191-198 (in Japanese).

[3] Kuwano, S., Namba, S., Shick, A., Höge, H,. Fastl, H., Fillipou, T., Florentine, T. and Moesch, H.: The timbre and annoyance of auditory warning signals in different countries, Proceedings of the International Congress on Noise Control Engineering, 2000, pp.3201-3206.

[4] Edworthy, J., Loxley, S. and Dennis, I.: Improving Auditory Warning Design: Relationship between Warning Sound Parameters and Perceived Urgency, Human Factors, Vol.33, No.2, 1991, pp.205-231.

[5] Stanton, N. and Edworthy, J.: Human Factors in Auditory Warnings, Gower Technical, UK, 1998.

[6] Namba, S., Kuwano, S., Kinoshita, K. and Kurakata, K.: Loudness and timbre of broad-band noise mixed with frequency-modulated sounds, Journal of the Acoustical Society of Japan (E), Vol.13, No.1, 1992, pp.49-58.

[7] Guo,S., Nakazawa, M., Ouchi, Y. and yamasaki, Y.: 1bit Alert Sirens, Proceedings of 1bit FOURUM 2005, 2005, pp.14-20 (in Japanese).

[8] ISO7731: Ergonomics-- Danger signals for public and work areas -- Auditory danger signals, 2003.

[9] ISO7029: Acoustics -- Statistical distribution of hearing thresholds as a function of age, 2000.

[10] Kuwano, S., Namba, S., Shick, A., Höge, H,. Fastl, H., Fillipou, T. and Florentine, T.: Subjective impression of auditory danger signals in different countries, Acoustical Science and Technology, Vol.28, No.5, 2007, pp.360-362.

[11] Yamauchi, K., Takada, M. and Iwamiya, S.: Functional imagery and onomatopoeic representation of auditory signals, Acoustical Science and Technology, Vol.59, No.4, 2003, pp.192-202 (in Japanese).

[12] Namba, S., Kuwano, S. and Mizunami, T.: Subjective evaluation of synthesized signals'', Proc. 3rd Jt. Meet. Between ASA and ASJ, 1996, pp.451–454.