A Study of Auditory Warning Signals for the Design Guidelines of Man-Machine Interfaces

Mie Nakatani[1], Daisuke Suzuki[2], Nobuchika Sakata[2], and Shogo Nishida[2]

[1] Osaka University, 1-16, Machikaneyama, Toyonaka, Osaka, Japan
mie@cscd.osaka-u.ac.jp
[2] Osaka University, 1-3 Machikaneyama, Toyonaka, Osaka, Japan
{suzuki,sakata,nishida}@nishilab.sys.es.osaka-u.ac.jp

Abstract. This paper presents an experimental study of the effects of respective sound parameters on human behavior in an emergency. 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 warning signals to assist the design of the warning systems. In this paper, the dynamic change of the sound parameters due to a degree of danger is focused. First, the reference values of parameters are settled by the reaction time experiment. Then the effect of dynamically change in parameters is subjectively evaluated.

Keywords: auditory warning signal, response time, pitch, frequency, waveform, psychological experiment.

1 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

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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 sociological 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.

2 Related Study

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 auditory signals in everyday situations. Various electronic sounds 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. This research 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] clarified the factors of sound image common to various daily signals. His research 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 to 5.0Hz, people recognized it as a warning or notice. When the modulating frequency of the signal was from 10.0Hz to 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.

3 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 changing 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 changing signals. We examine that changing the parameter of signals will control the dangerous impression.

At the first experiment, we determine the reference values of 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 reference values. 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.

4 Experiments

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

Procedure

A note PC and a headphone are used for the experiment(the left of Figure 1). These 80 signals are played in random order. Subjects are required to push a button between “Escape” or ”Not Escape” as soon as the signal is played. In addition, they are asked to select one among five descriptions for every signal(the right of Figure 1).

– This signal has no punch.
– This signal is appropriate. I can dispassionately evacuate.
– 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.

Subjects are sixteen, including university students and graduate students (13 males and 3 females. Age is from 22 to 25.)

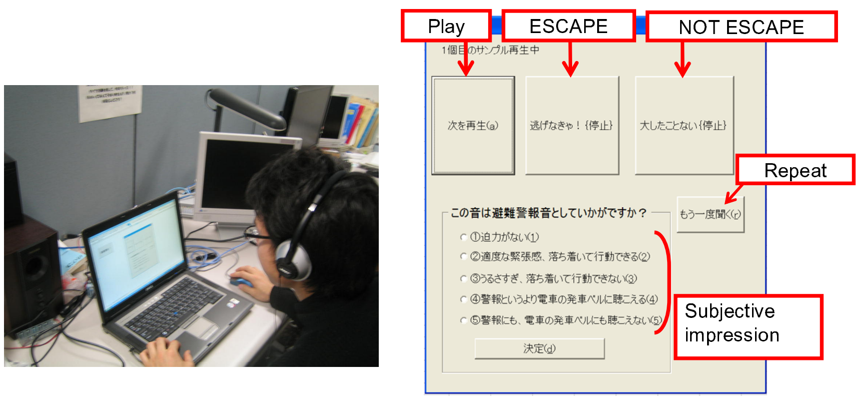

Fig. 1. A scene of the experiment and an example of the display

Result

Average time to evaluate 80 signals was about ten minutes per one subject. The higher limit of the response time to one signal is set to nine seconds. When the response time is over nine seconds, or “Not escape” or “Repeat” button is chose, the response time is regarded as ten seconds. Table 1 shows the map of the response time(second). The numeric value in each cell is the median.

Table 1. The response time (the median) of each signal

Sign wave (high -7dB) (second)

Frequency \ Modulation	1	2	4	8
160-320	10.00	10.00	10.00	10.00
320-640	10.00	10.00	9.50	10.00
640-1280	4.57	**2.73**	2.64	3.51
1280-2560	10.00	5.85	3.98	3.26
2560-5120	7.36	3.19	5.31	2.77

Sign wave (low -13dB) (second)

Frequency \ Modulation	1	2	4	8
160-320	10.00	10.00	10.00	10.00
320-640	10.00	10.00	10.00	10.00
640-1280	10.00	**3.00**	7.73	10.00
1280-2560	10.00	9.50	8.59	10.00
2560-5120	10.00	4.47	6.90	7.55

Square wave (high -10dB) (second)

Frequency \ Modulation	1	2	4	8
160-320	5.49	2.77	2.71	3.13
320-640	3.00	2.77	3.42	2.27
640-1280	3.20	**2.05**	2.52	1.68
1280-2560	3.63	3.16	2.05	1.63
2560-5120	4.43	3.45	2.70	2.18

Square wave (low -16dB) (second)

Frequency \ Modulation	1	2	4	8
160-320	10.00	9.50	2.71	10.00
320-640	5.01	3.58	2.81	3.13
640-1280	3.91	**2.24**	2.74	2.89
1280-2560	7.38	3.10	3.56	4.30
2560-5120	10.00	4.73	3.05	4.07

The shortest response time

Most subjects subjectively evaluate it as “appropriate”.

Focusing on frequency, about the signals from 160Hz to 640Hz of sign wave take long response time. These signals can’t make subjects evacuate. About the signals of 640Hz-1280Hz, the time is shorter in all tables.

Focusing on modulation period, the signals of 1Hz takes the longer time than others. Other modulation periods have no particular tendency.

Focusing on wave pattern, square wave has a tendency to take shorter time.

Focusing on Pitch, high pitch has a tendency to take shorter time with a few exceptions.

About subjective impression, the low- frequency signal is evaluated as “no punch”. The high-frequency signal is evaluated as “too noisy”. The signals of 640Hz-2560Hz has a tendency to be evaluated as “appropriate”.

On the whole, the result doesn’t show that the higher frequency or modulation period is, the shorter the response time is. The signals from 640Hz-2560Hz frequency and 2Hz-4Hz modulation period have the shorter response time. And these signals are also evaluated as subjectively “appropriate” by most subjects.

In Table 1, the bold-lined cells mean the shortest response time and the dotted cells mean best evaluation by subjective impression. Totally, we may use the 640Hz-1260Hz frequency and 2Hz modulation period as the reference values of parameters for the next experiment.

4.2 Experiment II

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, 640Hz-1260Hz frequency and 2Hz modulation period are set as the reference value of three steps. The parameters are changed as the following. We incrementally change these parameters on both sign wave and square wave.

- Pitch: sign 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 following 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 sign wave and square wave, so the total is 14 signals. Each signal is fifteen seconds (the parameters is changed every five seconds).

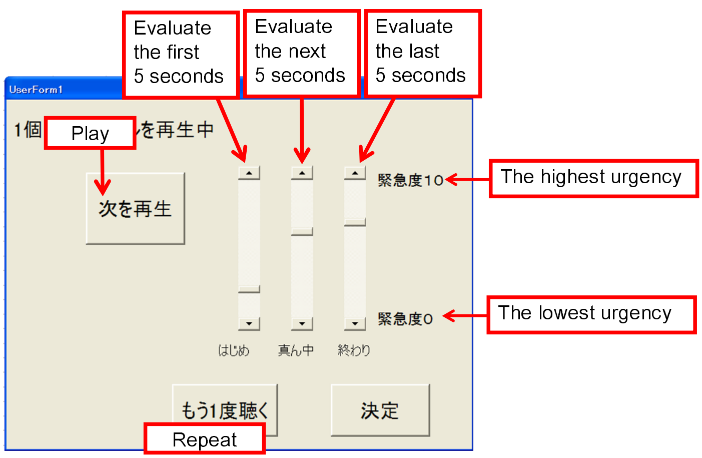

Fig. 2. An example of the display of the second experiment

Procedure

A note PC and a headphone are also used for this experiment. The 14 samples are played in random order. Subjects are required to evaluate the degree of urgency by sliding a bar when the signal is played(Figure 2). One signal is composed of three 5-second parts. 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.)

Result

Average time to evaluate 14 signals was about five minutes per one subject. The slide evaluation score is ranged from 0 to 9.

In Figure 3, the evaluation score of the reference value of parameter is center justified for comparison of all signals. When one parameter is changed, the degree of urgency increases slightly according to the incremented parameter. Among them, 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 3).

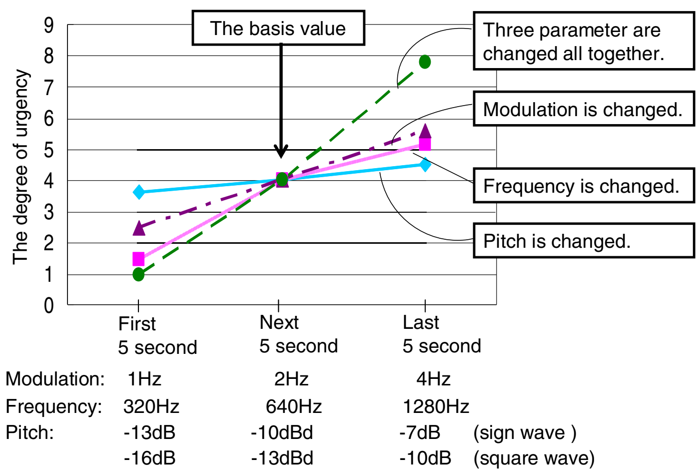

Fig. 3. The result when one parameter is changed and when three parameters are changed at a time

4.3 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 more anxious. Though it is uncertain that the response time is the best way as the evaluation method, the result shows that subjects respond at short times in the particular values of parameters. This suggests that the warning signals have the appropriate parameters.

The result of the second experiment suggests the possibility to control the impression of the warning signal. By combining the number and range of 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.

This time subjects are only students. We have to examine with subjects in a wide age range and compare with different cultures.

5 Conclusion

Today, disaster prevention and mitigation are the important problems. A lot of efforts have been done to minimize damage. To develop the appropriate evacuation calls is one of the tasks, because most people don't escape despite hearing the call. 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 cause a refreshing feeling. 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.

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