Experimental study of auditory warning types for ship bridge alert management system

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Abstract - **There are a lot of auditory warnings in the bridge, but again, not a great deal of research on the operator's ability to recognize and to interpret those warning sounds have been published. Therefore, this document carried out the groundwork for the operator's ability to recognize and interpret those warning sounds from an auditory sensory display. The "Auditory icon", which was previously studied by Leung (2001), was used to measure and compare with the existing alarm system (abstract sounds). Also, Japan provided the information (IMO, 2009) on their experiences of developing industrial standards for voice alarm/control system, based on Japanese Industrial Standards (JIS F 0062). On the basis of the results from the research, this paper attempts to be used as fundamental research in order to establish performance standards (suitable standards for recognizing and interpreting warning sounds) for an auditory warning (abstract sound, auditory icon, and voice alarm), and for integrating performance standard bridge warning alarms in order to establish the foundation of an Integrated Bridge Alarm System.**

Keywords
Bridge alert management, abstract sound, auditory icon, and voice alarm

INTRODUCTION

A main workplace of deck officers on ship bridge is equipped with various navigation instruments for ensuring safe navigation and it is an important workplace that pilot embarks and manoeuvres the vessel with her officers during entering or leaving a port. If the bridge system delivers wrong information or delivers by improper way to watch officers, it becomes a barrier that interrupts to recognize present situation exactly and to respond to it. Consequently, it can cause a fatal accident.

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The various kinds of indication equipments are used for delivering detailed information at the bridge and these indication equipments should be designed to deliver the information for deck officers as possible as quickly and exactly. In other words, it should be possible to check quickly whether something happens or not when there is an accident at the inside and outside of the vessel and it should be possible to make deck officers recognized exactly the reason why it happens. In the bridge of the vessel, visual display is mostly used in a general information delivery, but auditory display is mainly used in emergency situation information delivery. Auditory display can be more effective means than visual display in the following cases; message is simple or short; it doesn't need to refer for the future; it contains the information only at the time when it delivers; and it is a message or warning that demands immediate action (Sanders and McCormick, 1987).

Auditory warning is one of the auditory indication equipment that can deliver information effectively in emergency situation or during equipment failure. The type of auditory warning is largely divided into voice alarm, abstract sound and auditory icon.

Voice alarm is a warning that delivers information about present warning situation in the form of human voice. Voice alarm favors to deliver complex contents information and has a merit that it hardly needs to learn on warning situation. (Simpson, 1987) But, in case of high peripheral noise level or much voice-similar frequency noises, voice alarm can be masked by these noises.

Abstract sound is a type of auditory warnings that we can hear most commonly and it is the warning to deliver information by the tone and rhythm of a simple beep type. Abstract sound has two merits. One is to minimize the phenomenon masked by ambient voices and another is to deliver information quickly. But, there is a limit that 5 ~ 9 kinds of sound because it is difficult to learn and remember a kind of abstract sound on each warning situation. In case of vessel, almost all auditory warnings are consist of abstract sounds and officers actually respond the situation by searching the position of warning producing equipment following sounding direction rather than by recognizing warning situation that ringing sound means. Therefore the cases that inform the position information of warning producing equipment are more prevalent than the cases of quick and correct information delivery. Consequently if many auditory warnings that inform vessel's dangerous situation ring simultaneously with ambient noises, especially when vessel precedes the waters like narrow channel, she can run into danger because it is difficult to respond quickly.

Auditory icon is a warning sound that uses an environmental sound in other words, a natural sound (Ballas etc., 1987; Gaver, 1986). For example, it is the way to warn fire warning situation by presenting firewood crackling sound. Auditory icon is a sound of different type with abstract sound and voice alarm and has a potentiality that can be used for the effective auditory warning. Auditory icon shares benefits of abstract sound and is different with it because a kind to be learned is not limited. Lawrence and Banks(1973) showed that the human's memory capacity of environmental sound is possible up to 194-item set through an experiment study. The experiment study on effect of the auditory icon is partly continued. Leung(2001) made voice alarm, abstract sound and auditory icon on certain circumstances and measured respectively the number of total performance times and the number of error until subjects answered it correctly. As a result, he reported that there was no significant difference of error rate between voice alarm and auditory icon but abstract sound had a significant difference with voice alarm and auditory icon. Lee Bong Wang and others (2005) reported that auditory icon elevated correct answer rate in comparison with abstract sound in the recognition experiment which compared correct answer rates after presenting bridge-produced warning situation by using abstract sound and auditory icon.

Generally, in the bridge, there is a working circumstance that actual verbal communication that needs for working performance, various auditory signals and unwanted noises co-exist. But the study that analyzes synthetically an effect on human recognition ability caused by warning sounds is insufficient. And these sounds are divided broadly into voice alarm, abstract sound and auditory icon depending on each different warning situation in this circumstance. This study is conducted to recognize how human respond accuracy, respond time and subjective satisfaction level change depending on the type of warning situation and auditory warning sound in the bridge working circumstance.

HOW TO DO EXPERIMENT

Subjects

25 persons in 1 ~ 3 class COC holding deck officers joined the experiment, which were normal in their eyesight and hearing and had personal computer using experience. Seagoing year of subjects was average 7.6 years and their age was average 40.6 years.

Experiment equipments

For the experiment PC (P-4 1.8GHz), LCD color monitor (17 inches, Resolution 1024×768), Mouse, Head-set (SHS-100V), MFC (Microsoft Foundation Class Library) and simple calculation question papers were used. PC and monitor including mouse were used for subjects to input their information and to respond to choose warning situation at which they recognize during experiment and head-set were used to block the subjects from ambient noise and to present experiment-used warning sound and VHF between vessels to them.

MFC library based on C++ randomly presented experiment conditions that combined warning situation and warning sound that were embodied in the experiment at 2 minutes interval. It was also used to express a warning situation button to be chosen by subjects on the monitor and to frame the program that records the results. Containing simple questions (ex.1+2=), calculation question paper was used to solve the questions at the course at which the subjects carry out an experiment task in the form of secondary task. It purposed to embody experimental workload in similar condition as possible as real voyage workload and simultaneously to minimize that the subject forecasts warning situation or concentrates only on a PC monitor.

Experiment plan

Independent variable for the experiment was processed as three levels of warning sound type and five levels of warning situation and then was measured repeatedly in total fifteen (3 x 5) combination conditions. Three types of warning sound type meant three kinds of sound presented to the subjects and were consist of abstract sound, auditory icon and voice alarm as mentioned in the introduction. Five levels of warning situation indicated breakdown, dangerous situation namely what contents of information was and were processed as fire, steering, electricity, collision, and engine. Table 1 shows how to embody three types of warning sound type depending on each five levels of warning situation. Abstract sound used a recording of representative warning sound used in actual bridge as a sound source and auditory icon and voice alarm used an extract from the KORDI (Korea Oceanographic Data Center) data as a sound source.

Dependent variable was collected the data on the basis of response accuracy, response time and subjective satisfaction level. Response accuracy was computed from the ratio that subjects choose correctly and respond on each presenting warning sound type and warning situation. Response time was measured by the time required until the subjects pushed a suitable warning situation button displaying on the monitor at each experiment conditions after hearing warning sound. Monitor-displayed warning buttons were designed as total 10 kinds (fire, steering, collision, engine, GPS, internal line, external light, fore light and VHF) and it purposed to minimize the learning effect that if it used only 5 experiment-demanding warning situation buttons (fire, steering, electricity, collision and engine), subjects learned the button positions in the experiment process so it can effect reaction time as experiment is advancing.

Subjective preference level was measured with 7 point scale in subjects' total preference level to warning sound type immediately after carrying out experiment and getting closer to point 1 means "extremely dissatisfied" and getting closer to point 7 means "very satisfied".

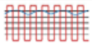
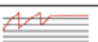
Warning situation	Warning sound type		
	abstract sound	auditory icon	voice alarm
Fire		The sound of wood burning	Fire
Steering		The sound of manipulate a rusty steering	Steering failure
Electricity		The sound of machine lost electric power	Low power
Collision		The sound of strong waves	Warning collision
Engine		The sound of the engine is turned off slowly	Engine failure

Table 1. Level and the way of embodying warning sound type and situation

Experiment procedure

Prior to experiment, the subjects received explanation about experiment procedure and filled in the questionnaire that asked their physical condition and whether they had any factor effecting to the experiment or not. After finishing filling in the questionnaire, it provided the training opportunity about 15 test conditions to be used in the experiment to the subjects. Subjects studied mainly with a training to recognize proper warning situation after hearing abstract sound, auditory icon and voice warning by using experiment PC for 5 minutes.

In the main experiment that was progressed immediately after training, the subjects that sit in front of the PC monitor with wearing a headset clicked the experiment-starting button after inputting PC monitor-displayed their personal information and then began to solve the calculation question paper. They were instructed to solve calculation questions exactly and quickly. Also after clicking the experiment-starting button, to create the circumstance similar to real inner-bridge, it let the subjects hear vessel radio communication through their wearing headset by playing continually.

In the experiment progressing process, the subjects heard one warning sound of 15 conditions (warning sound type 3 levels × warning situation 5 levels) that was randomly embodied once in about 2 minutes and chose one correctly-judged button of 10 monitor-displayed warning situation (fire, steering, electricity, collision, engine, GPS, internal line, external light, fore light and VHF) buttons and then started again to solve the calculation question after choosing it.

After completing to record every experiment condition, the subjects evaluated subjective satisfaction level that they felt with 7 point scale to abstract sound, auditory icon and voice alarm and then experiment was terminated.

EXPERIMENT RESULTS

To analyze experiment result, it carried out analysis of variable (ANOVA) to data that measured response accuracy, response time and subjective satisfaction level by using statistical analysis software, Statview (5.0). In result of ANOVA, it carried out Tukey/Kramer's multiple comparisons to the significant factors. It set up statistical significance level as totally 5%.

Response accuracy

Because response accuracy, one of dependent variable collected from the experiment, had a characteristic of qualitative variable, it carried out ANOVA after processing it as coefficient data, which assigned correct choice to "1" and wrong choice to "0".

In result of carrying out ANOVA to response accuracy, it showed that main effect of warning sound type ($F_{2, 360} = 27.841$, $p < 0.0001$) and main effect of warning situation ($F_{4, 360} = 6.369$, $p < 0.0001$) were significant at 5% significance level. And it was analyzed that interaction of warning sound type x warning situation was not significant ($F_{8, 360} = 1.223$, $p = 0.2841$). Table 2 shows the result of ANOVA to response accuracy.

	DF	SS	MS	F-value	p-value
warning sound type	2	10.864	5.432	27.841	<.0001*
warning situation	4	4.971	1.243	6.369	<.0001*
warning sound type × warning situation	8	1.909	.239	1.223	.2841
residual	360	70.240	.195		

* : Significant at the Level 0.05(5%)

Table 2. ANOVA table for response accuracy

Table 3 shows Tukey/Kramer analysis result, that carries out multiple comparisons of warning sound type that indicates main effect is significant in ANOVA and Figure 1 shows average accuracy of warning sound type (unit: percentage) at each level. According to the figure, it can be understood that response accuracy is most excellent as average 0.824 (82.4%) when using voice alarm and accuracy lowers in order of auditory icon 0.64 (64%), abstract sound 0.408 (40.8%) According to Tukey/Kramer analysis result, accuracies at these three levels have statistically significant differences.

Tukey/Kramer for accuracy Effect: warning sound type Significance Level: 5%			
	Mean Diff.	Crit. Diff	
Abstract sound, Auditory icon	-.232	.131	S
Abstract sound, Voice Alarm	-.416	.131	S
Auditory icon, Voice Alarm	-.184	.131	S

S : significance to difference of average between levels

Table 3. Response accuracy multiple comparison between levels of warning sound type

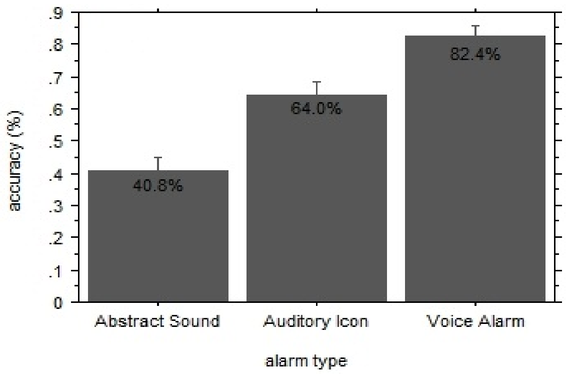


Figure 1. Average response accuracy at each level of warning sound type

Response time

Response time is the seconds-unit-measured data from the time taken the subjects to choose warning situation button under each experiment conditions. Only the data of case to choose correct button was used for the response time ANOVA.

In result of carrying out AVOVA to response time, it showed that main effect to warning sound type ($F_{2, 218}$ = 4.849, p = 0.0087) and main effect to warning situation ($F_{4, 218}$ = 6.393, p < 0.0001) were significant at 5% significance level. And it was analyzed that interaction of alarm type x alarm situation was not significant ($F_{8, 218}$ = 0.137, p = 0.9975). Table 4 shows the result of ANOVA to response time.

	DF	SS	MS	F-valus	p-valus
warning sound type	2	105.431	52.716	4.849	.0087*
warning situation	4	278.009	69.502	6.393	<.0001*
Warning sound type × warning situation	8	11.903	1.488	.137	.9975
residual	218	2370.112	10.872		

* : Significant at the Level 0.05(5%)

Table 4. ANOVA table for response time

Table 5 shows Tukey/Kramer's result, which carried out multiple comparisons of warning sound type that indicates main effect was significant in response time ANOVA and Figure 2 shows a comparison of the average response time(unit : second) at each level of warning sound type. According to the figure, it was analyzed that response time was shortest as average 5.857 sec when using auditory icon and it increased to 6.343 sec in voice alarm and 7.612 sec in abstract sound. However, According to Turkey/Kramer's analysis result, auditory icon had statistically significant difference in response time in comparison with abstract sound but it couldn't find significant difference between auditory icon and voice alarm.

Tukey/Kramer for time Effect: warning sound type Significance Level: 5%			
	Mean Diff.	Crit. Diff	
Abstract sound, Auditory icon	1.755	1.395	S
Abstract sound, Voice Alarm	1.269	1.341	
Auditory icon, Voice Alarm	-.486	1.164	

S : significance to difference of average between levels

Table 5. Response time multiple comparison between levels of warning sound type

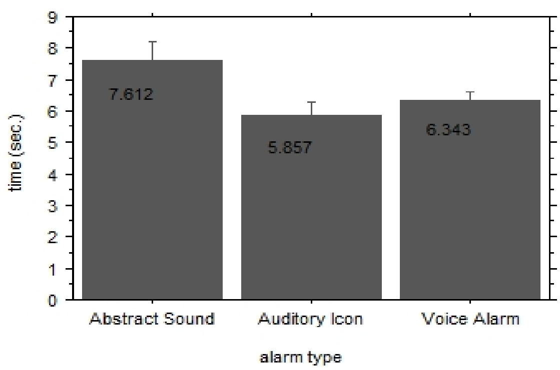


Figure 2. Average response time at each level of warning sound type

Subjective preference level

Subjective preference level is a data that subjects evaluated their subjective preference level to three level of warning type, that is, abstract sound, auditory icon and voice alarm with 7 points scale. In result of ANOVA to preference level, main effect of warning sound type was significant ($F_{2,72} = 25.32$, $p < 0.0001$). Figure 3 shows average preference level according to warning sound type. In result of Tukey/Kramer's multiple comparison, preference level to voice alarm (Ave. = 6.04) was significantly higher than preference level to abstract sound (Ave. = 3.16) and to auditory icon (Ave. = 3.08). However, there was no significant difference of preference level between abstract sound and auditory icon.

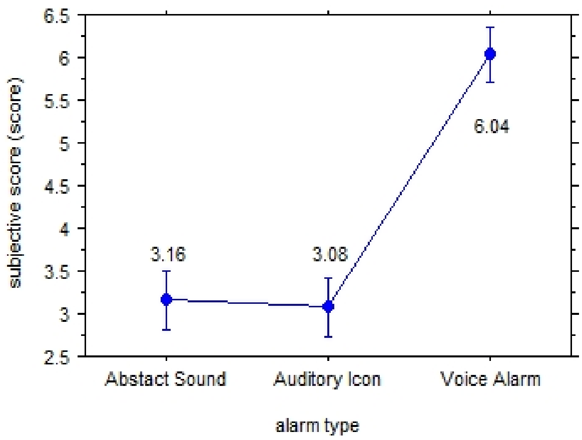


Figure 3. Average of subjective preference level according to warning sound type

DISCUSSION AND CONCLUSIONS

This study was conducted to analyze synthetically the effects of the auditory warning sound types that are either in use or under consideration for use in various warning situations in ship's bridge of ship system. Auditory warning sound type includes abstract sound that is mainly used in present Korean ship, auditory icon and voice alarm that are considered as alternatives in experiment study and integrated bridge design. And the effects of warning sound type were analyzed by the measure of response accuracy, response time and subjective preference level.

In the result of analyzing experiment for response accuracy, the response accuracy of subject was most excellent when it used voice alarm (82.4%) and accuracy went down in order of auditory icon (64%), abstract sound (40.8%). And this accuracy difference was statistically significant. The Voice Alarm has an inherent advantage of accurate communication however it has a disadvantage that is shielded by peripheral noise and similar frequency sounds. In this experiment, despite that it was estimated that there was some shield effect by presenting actual inter-vessel communications as background noise, voice alarm maintains its superior accuracy against other two warning sound types.

In the other hand, the response accuracy of abstract alarm, which was judged to be familiar with experiment participating deck officers because it is most widely used, was most inferior. This result is judged not to be unrelated with not only the reason why abstract sound, which is used according to alarm situation in various bridge systems, is not standardized but also instinctive problem of abstract sound that meaning is indefinite.

In the aspect of response time, the subject showed the quickest responses to auditory icon. But although voice alarm also had a little longer average response time, the difference between auditory icons was not statistically significant. Nevertheless it was not significant difference, the reason why response time of voice alarm is longer than response time of auditory icon is judged from that response choice was some delayed because inter-vessel communication presented as background noise during experiment is shield with voice alarm. As a result, it is possible to analyze that auditory icon and voice alarm are at similar level in the aspect of response time and abstract sound shows slower response in comparison with the aforementioned two.

Separately from the objective evaluation according to analysis about response accuracy and response time, preference level that experiment participating deck officers felt subjectively was evaluated with 7 points scale (Closer to 7, more satisfied). According to analysis result, preference level to voice alarm was average 6.04 and it showed significantly higher preference level in comparison with abstract sound(average 3.16) and auditory icon(average 3.08).

In synthetic view of the above analysis result, it is judged that voice alarm is the most excellent auditory warning sound type. Voice alarm demonstrates superior results in the aspect of response accuracy and subjective preference level against auditory icon and abstract sound. And it also does not demonstrate significant response time difference in comparison with auditory icon that is shortest.

Auditory icon that shows shortest response time also has a possibility to be considered as an alternative of auditory warning in ship bridge. Lower subjective preference level and response accuracy in comparison with voice alarm may be due to a limited training time before experiment. Hereafter, it demands an additional study that offers sufficient training time to be familiar with auditory icon and analyzes a change of response time and accuracy according to training time.

This study simply individually compared and analyzed three warning sound types. Hereafter it is judged to need a study about new warning sound type that presents these three warning sound type compositively in order or repetitively. For instance, a warning sound type, which orderly presents fastest auditory icon and most accurate voice alarm, can be considered.

Finally, the result of this study should be interpreted within the limits of laboratory-applied warning situation and working circumstance condition. Although experiment presented inter-vessel communication as a background noise and imposed calculation question work to lay voyage workload, hereafter more actual study, through an experiment on actual vessel or in the simulator using voyage work circumstance, is hoped.

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