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DEVELOPMENT OF AN ALARM SOUND DATABASE AND SIMULATOR

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ABSTRACT. Objectives. The purpose of this study was to develop an interactive software package of alarm sounds to present, recognize and share problems about alarm sounds among medical staff and medical manufactures. **Methods.** The alarm sounds were recorded in variable alarm conditions in a WAV file. The alarm conditions were arbitrarily induced by modifying attachments of various medical devices. The software package that integrated an alarm sound database and simulator was used to assess the ability to identify the monitor that sounded the alarm for the medical staff. **Results.** Eighty alarm sound files (40MB in total) were recorded from 41 medical devices made by 28 companies. There were three pairs of similar alarm sounds that could not easily be distinguished, two alarm sounds which had a different priority, either low or high. The alarm sound database was created in an Excel file (ASDB.xls 170 kB, 40 MB with photos), and included a list of file names that were hyperlinked to alarm sound files. An alarm sound simulator (AlmSS) was constructed with two modules for simultaneously playing alarm sound files and for designing new alarm sounds. The AlmSS was used in the assessing procedure to determine whether 19 clinical engineers could identify 13 alarm sounds only by their distinctive sounds. They were asked to choose from a list of devices and to rate the priority of each alarm. The overall correct identification rate of the alarm sounds was 48%, and six characteristic alarm sounds were correctly recognized by between 63% to 100% of the subjects. The overall recognition rate of the alarm sound priority was only 27%. **Conclusions.** We have developed an interactive software package of alarm sounds by integrating the database and the alarm sound simulator (URL: http://info.ahs.kitasato-u.ac.jp/tkweb/alarm/asdb.html). The AlmSS was useful for replaying multiple alarm sounds simultaneously and designing new alarm sounds interactively.

KEY WORDS. Alarm sound, multimedia database, WAV file, simulator.

INTRODUCTION

Medical devices have generated alarm signals since the 1980s. Auditory alarms are particularly useful because they can call an attendant's attention to clinical events [1–3]. Along with the growth of clinical instrumentation in intensive care areas, there has been a rapid increase in the number of audible "alarms" concentrated within these areas [4, 5]. This proliferation of alarm signals, particularly of the auditory variety, is causing problems [1, 4, 6, 7]. Problems include difficulty in identifying the source of an alarm signal, loud and distracting alarm signals besides false positive or false negative alarms [7–12]. This is because most of the audible warning devices sound very similar

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in tone [13, 14], possibly because most alarm systems are made by the same company [13]. In addition, monitors made by different companies have different alarm sounds for the same variable, and similar alarm sounds for different variables [11]. There was no good data to support the use of a particular system of alarm tones in the operating room [15, 16]. The use of the Patterson sounds that may be the de facto international standard of alarms remains controversial [15]. Many investigators have pointed out that audible signals should be standardized [2, 7, 9, 11, 12, 16–21]. Williams et al. [22] tested an intrinsic learn ability and urgency mapping characteristics of Block et al. system [16], and pointed out that a poor within priority class performances were ascribable to a priori aspects of the design of sound system [22]. Mondor et al. [2] concluded that the alarms currently used do not convey the intended sense of urgency to naïve, new, or inexperienced listeners, and that manufactures would do well to engage in more thoughtful alarm design. We made an application package of alarm sounds to simply present and experience hearing actual alarm sounds and to interactively design better alarm sounds.

METHODS AND MATERIALS

System description

The system is composed of the alarm sound database, recorded alarm sounds and the alarm sound simulator (Figure 1). The alarm sound database stores information of each alarm sound: the manufacture, name of the machine, machine model, picture, alarm priority, alarm sound profile, fundamental frequency, an A-weighted sound pressure level, technical alarm condition and a file name of the sound. An item with the file name was then hyperlinked to an alarm sound file as described below.

In order to sound various alarms artificially, each alarm condition was induced by modifying attachments of each medical device. For example, an artificial ventilator was connected with a tracheal tube and a test lung. Artificial accidents were induced by occluding the tracheal tube, loosening a connector, compressing the right test lung, etc. An infusion pump was attached with a set of a bottle and fluid line. A power attenuator was used to induce the state of a power failure.

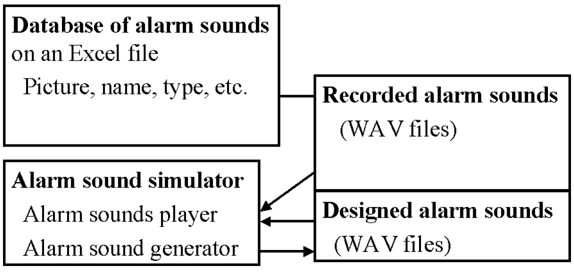


Fig. 1. Structure of the system.

Alarm sounds were measured by a noise meter (NA27, Kyushu Rion, Hakata, Fukuoka, Japan) to quantify A-weighted sound pressure level and harmonics energy at a one-meter distance from a machine [23]. A maximum and minimum alarm sound pressure was measured for devices that have an adjustable alarm volume level. The alarm sounds were recorded near the machine by digital voice recorder (ICR-S300RM, SANYO, Osaka, Japan). The recorded sounds were stored in WAV files with sampling frequencies of 44.1 kHz and 16-bits resolution per sample. The fundamental frequency of each alarm sound was analyzed using the FFTAnlyzer (E.N. Software, http://www.vector.co.jp/soft/winnt/art/se259149.html).

The alarm sound simulator (AlmSS) has a player module and a generator module. The player module simultaneously replays multi-WAV files to reproduce an urgent situation such as in an operating room. The generator module creates various new alarm sounds under ISO recommendations for alarm sounds [2, 17]. The alarm sound is defined by the number of pulses in a burst, pulse spacing, burst spacing, repeat time, pulse frequency, effective pulse duration, rise time and fall time. The designed alarm sound is stored in a WAV file.

The AlmSS was used to assess the ability of 19 clinical engineers to identify the alarm sources and conditions responsible for the alarm sounds. These engineers were accustom to hearing many alarms in operating rooms and/or intensive care units (ICUs) every day and many times a day. Testing took place in a relatively quiet room. Thirteen sounds actually played were sequentially listed with their alarm sound priorities, profiles and conditions (Table 1). Six characteristic sounds (‘a’ to ‘f’ in Table 1) were tested at first followed by 7 simple sounds (‘g’ to ‘m’) composed of beep sounds. Sounds were presented at a comfortable volume, and some were repeated two or three times as requested. The subject was asked to select from a list of machines the one that they thought had generated the alarm sound, and to score in their opinion the perceived urgency of the sound. The list contained one entry for each of 13 devices and the entry, “Unrecognizable.” The clinical experience (years of clinical engineering) for each subject was recorded. Identification rates of each subject and recognition rates for each sound were calculated. The recognition rates for alarm priorities were calculated.

Table 1. List of alarm sounds for test procedure

Sound	Category	Manufacture, model	Priority	Profile	Fundamental frequency (Hz)	Alarm conditions	Sound file name (.wav)
a	Pulse oximeter	tyco Healthcare, N-550(1)	Medium	Beep	754	Pulse rate low or high, A1	N550-1-midle
b	Electrosurgical unit	ACOMA, Acutor S	High	Buzzer	530	Earth failure, A2	Actool
c	Monitoring system	Nihon Koden, BSM-7201 BSM-7211	High	Pulses	1140	Apnea, A3	LifeScope8alarmhigh
d	Artificial ventilator	Respironics, BiPAP Synchrony	High	Pulses	2600	Apnea, A4	BiPAPHSout
e	Monitoring system	Colin Medical Technology , NX BP-88	High	Pulses	1100	disconnected SpO_2 probe	NX-BP-88-mid
f	Pulse oximeter	NELLCOR PURITAN BENNETT, NPB-290	High	Beep	935	NPB-290-high.wav	NPB-290-high
g	Artificial ventilator	Newport Medical Instruments, Newport E100	High	Beep	3740	Airway pressure low	NewportE100-airlow
h	Syringe driver	TERUMO, TE-332, TE-332S	High	Beep	3754	Low battery	TE-332-lowbattery
i	Blood warmer	Toray Medical, TM-90	High	Beep	2240	Temperature failure	TM-90
j	Infusion pump (C1)	NIPRO, Carrica pump CP-300	Medium	Beep	4515	Status opened, A5	Caricapump
k	Hyperthermia system	GAYMAR, MEDI-THERM	Medium	Beep	2725	Confirm sensor	MEDI-THERM
l	Artificial ventilator	NELLCOR PURITAN BENNETT, LP6	High	Beep	2800	Apena, A6	LP6
m	Artificial ventilator	Pulmonetic Systems, LTV 1000	High	Beep	2865	Apnea, A7	LTV

C1–Infusion pump for central venous nutrition; A1 – SpO2 low or high, Set second function Alarm; A2 – Grounding pads failure, over heat; A3 – HR upper limit/lower limit, Blood pressure upper limit/lower limit, SpO2 low or high, Arrhythmia (VF, Asystole, VT); A4 – disorder in airway pressure, PEEP or ventilation volume; A5 – tube unfasten; A6 – disorder in airway pressure; A7 – Airway pressure low/high, low battery, no battery, low ventilation volume, disorder in gas supply, PEEP or low external power supply.

Table 2. The number of medical device artificially induced alarm sounds

Category	Type of medical device	*n*
Cardiac	Anesthesia workstation	2
Ventilation	Artificial ventilator	10
Oxygen	Biophenomena monitoring system	4
	Pulse oxymeter	3
	Oxygen monitor	1
	ECG data processor	1
Temperature or energy delivery	Electrosurgical unit	3
	Hyperthermia equipment	2
	Blood warmers	1
	Defibrillator	1
	Nebulizer	1
	Heated air humidifiers	1
Drug or fluid delivery	Syringe drivers	4
	Infusion pumps	3
	Infusion pump for central venous nutrition	2
	Infusion pump for parenteral nutrition	1
Other	Massager	1

n = number of medical devices tested.

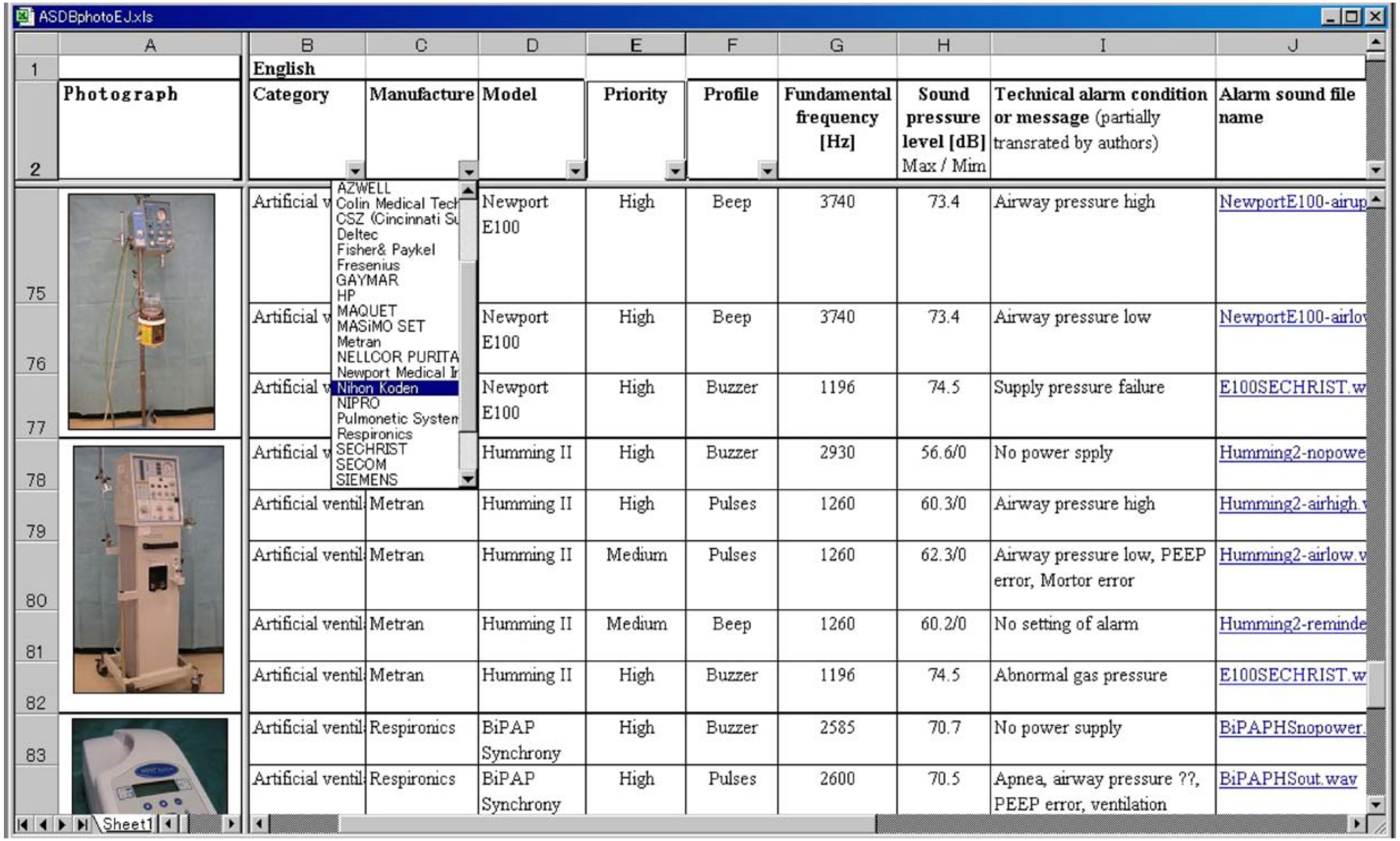
RESULTS

Eighty alarm sound files were recorded from 41 medical devices made by 28 companies (Table 2). Examples of technical alarm conditions were listed in Table 3. These alarm conditions and messages were collected from original device manuals. There were some local terms in the alarm conditions and messages that were specific to the machines and manufactures. The alarm database was constructed on a spreadsheet of an Excel file (ASDB.xls, 130 kB without photographs, and ASDBphoto.xls, 40 MB with photographs) (Figure 2). The spreadsheet stored 91 records, each of which contained 9 items: type of device, name of manufacturer, machine model, alarm priority, alarm sound profile, fundamental frequency, A-weighted sound pressure level, technical alarm condition and file name of alarm sound.

The alarm priorities of each alarm condition were classified into four categories according to ISO, high, medium, low and informative. There were 51 records in the high priority category, 23 in the medium and 17 in the low category. The alarm sound profiles were classified by musical impressions into five patterns: a continuous simple sound without a pause (Buzzer), a simple sound with a pause (Beep), a continuous harmonized sound (Siren), bursts composed of various pulses (Pulses), a damping burst pattern (Chime). There were 14 records in the Buzzer type, 22 in the Beep type, 8 in the Siren type, 35 in the Pulse type and 12 in the Chime type. Fundamental frequencies of alarm sounds were varied from 495 to 4810 Hz. A maximum sound pressure level of each machine was varied from 49.8 to 95.1 dB, a minimum level from 0 to 79.2 dB. There were three pairs of the similar alarm sounds that we could not easily discern from each other (Table 4). The alarms of the first pair had a different priority, both low and high. The third pair impressed us a similar melody in spite of the different fundamental frequency. Each file name of an alarm condition in the Excel file was hyperlinked to a sound file to simply play the sound. Some file name were hyperlinked to the same sound file according to the machine manual.

The AlmSS (AlmSS.exe, 260 kB) was developed in Visual C++ 6.0 with the Microsoft Foundation Classes version 4.2. The window of AlmSS was composed of a player panel in the upper area and a generator panel in the lower area (Figure 3). The player panel provided three sets of setting buttons of WAV file names, play or stop buttons and check boxes for repeat mode. The player module was able to simultaneously play a maximum of three alarm sounds while drawing sound profiles on a graphics box in the middle area. The number of simultaneously playing sound files was restricted by other CPU tasks, which could have been caused by the memory control of the Windows operating system. In the generator panel, a pulse profile of a new alarm sound was defined by a period, duration, rise time (Tr), fall time (Tf), fundamental frequency, the number of repeated bursts or pulses, pauses according to the ISO recommendations, and an optional fade-out mode. Four bursts could be interactively created by setting buttons and scrollbars. Sound characteristics recommended by the ISO format, a pulse spacing (Ts), burst interval (Tb) and effective pulse duration (Td) were automatically calculated from the parameters above and described in a lower edit box. The new alarm sound was interactively and repeatedly played in a design phase. The new alarm sound is then saved in a WAV file and named.

Nineteen volunteers were recruited from the Kitasato University Hospital and Kitasato University East Hospital staffs. All the responses of the subjects are shown (Tables 5 and 6). Correct answers are shaded grey. The overall identification rate of the alarm source was 48% with a range of 7% to 69% (in the bottom line of Table 5). Subject S had the best performance identifying 9 alarms correctly (69%), and Subject K had the worst performance (7%), identifying only 1 alarm correctly, even though having had more than 10 years of experience. Recognition rates of alarm sounds



	A	B	C	D	E	F	G	H	I	J
1		English								
2	Photograph	Category	Manufacture	Model	Priority	Profile	Fundamental frequency [Hz]	Sound pressure level [dB] Max / Mim	Technical alarm condition or message (partially transrated by authors)	Alarm sound file name
75		Artificial v		Newport E100	High	Beep	3740	73.4	Airway pressure high	NewportE100-airup
76		Artificial v		Newport E100	High	Beep	3740	73.4	Airway pressure low	NewportE100-airlov
77		Artificial v		Newport E100	High	Buzzer	1196	74.5	Supply pressure failure	E100SECHRIST.w
78		Artificial v		Humming II	High	Buzzer	2930	56.6/0	No power spply	Humming2-nopowe
79		Artificial ventil	Metran	Humming II	High	Pulses	1260	60.3/0	Airway pressure high	Humming2-airhigh.v
80		Artificial ventil	Metran	Humming II	Medium	Pulses	1260	62.3/0	Airway pressure low, PEEP error, Mortor error	Humming2-airlow.v
81		Artificial ventil	Metran	Humming II	Medium	Beep	1260	60.2/0	No setting of alarm	Humming2-reminde
82		Artificial ventil	Metran	Humming II	High	Buzzer	1196	74.5	Abnormal gas pressure	E100SECHRIST.w
83		Artificial ventil	Respironics	BiPAP Synchrony	High	Buzzer	2585	70.7	No power supply	BiPAPHSnopower.
		Artificial ventil	Respironics	BiPAP Synchrony	High	Pulses	2600	70.5	Apnea, airway pressure ??, PEEP error, ventilation	BiPAPHSout.wav

Fig. 2. A sample screen of the alarm sound database.

Table 3. Examples of alarm conditions and messages

Causes	Examples of alarm conditions and messages
General	Start reminder, no operation, no setting of alarm, reminder alarm, outside setting, over setting, non-invasive blood pressure upper limit/lower limit, supply pressure failure, leads off, plunger/clutch disengaed, internal failure, etc.
Cardiac	Arrhythmia alarm, arrhythmia (bradycardia, tachycardia), arrhythmia (VPC run, couplet, early VPC, bigeminy, frequent VPC), arrhythmia (VF, asystole, Vf/VT, ext brady), pulse rate high and low limits, lower limit of pulses, upper limit of pulses, heart rate upper/lower limits, high and low limit for systolic pressure, leads off, break off of earth line
Ventilation	Respiratory rate upper limit/lower limit, apnea, PEEP error, disconnection with patient, loose connection, circuit disconnected, circuit tube unfasten, tidal volume sensor disconnected, maximum or minimum pressure threshold, failures in the fresh gas flow system, system pressure failure, system pressure low, system pressure high, airway pressure high, air way pressure low, pressure low, pressure high, low inspiratory pressure, flow failure, tidal volume unset, FiO_2 upper limit/lower limit, etc.
Oxygen	Low ogygen in oximeter, oxygen failure, gas supply failure, supply pressure failure, pulse search, siganl loss, probe off, disconnected SpO_2 probe, SpO_2 upper limit/lower limit, maximum or minimum threshold of SpO_2, no battery of transmitter
Temperature/Energy delivery	Temperature upper limit/lower limit, low body temperature, over heat, high frequency current over, probe failured or disconnected, low water level, failure of water temperature sensor, confirm sensor
Drug or fluid delivery	Occlusion, obstruction in the circuit, high delivery pressure, air bubble enters the fluid line, air-in-line, disconnection, flow malfunciton, line empty alarm, nearly empty, bottle empty, low reservoir-residual volume, completion, pump in stop mode, door open, syringe unfasten, tube unfasten, bottle unfasten
Equipment or supply failure	Battery in use, low battery, no battery, no power supply, power failure

varied from 5% to 100% (in the right column). The 6 sounds ('a' to 'f') that had impressive characteristics were all recognized by 12 subjects and the recognition rates of the sounds were from 63% to 100%. The overall recognition rate of the alarm sound priority was 27%, and only 4 alarm sound priorities ('a', 'c', 'f' and 'k') were correctly recognized by more than 50% of the subjects (Table 6).

DISCUSSION

We have searched for alarm sound databases of medical devices on the Internet by well-known search engines and in PubMed with the key words, "alarm sound," "database" and "medical device." However, we have not found any alarm sound databases expect our own. Our database plays the actual warning sounds. A few reports described characteristics of alarm sounds in a table [2, 9, 16], some musical knowledge is necessary to actually know what it is. Although the IEC/ISO joint working group on medical equipment alarm systems has proposed a new set of auditory alarm sounds [9, 24], the alarm sound database is needed to actually hear and easily learn the differences between the sounds. Our database includes 80 alarm files recorded from 41 medical devices. We found three pairs of similar alarm sounds from the actual sound database (Table 4). One pair presents the same sound that was implemented for different priorities, high and low, in the two medical devices. Although, to our knowledge there has been no studies or statistical analyses to confirm a similarity of sounds in an operating room or ICU, we could not discern them from each other. Medical staffs and manufactures should be made aware of this evidence. The list may be the first clear description of similar alarm sounds of its kind.

Although there is no technical problem in constructing an alarm sound database on Excel, it took a considerable length of time to artificially recreate, record and store many alarm sounds. Because most of the medical devices have no operation buttons to sound the alarms intentionally, alarm conditions were simulated by setting the appropriate attachments to each medical device. Therefore, to properly train medical staffs, many complex preparations must be done. However, our database presents various recorded alarm sounds in real time without requiring an inordinate amount of time and space for training. The database can be used both as a testing and learning tool for identifying alarm sounds.

The correct identification rates for subjects, mean rate 48%, are the same as in other reports [14, 25, 26]. Most correct answers were in 6 sounds ('a' to 'f'). Recognition rates of the 6 sounds were 63% to 100% and recognition rates of other sounds ('g' to 'm') were poor (5% to 31%)

Table 4. List of similar alarm sounds

Category	Manufacture, model	Alarm conditon	Priority	Profile	Fundamental frequency (Hz)	Sound pressure level (dB)	Sound file name
Syringe driver	TERUMO, TE-331S	Low battery	Low	Beep	3754	76.4	TE-332-lowbattery.wav
Artificial ventilator	Newport, Newport E100	Low airway pressure	High	Beep	3740	73.4	NewportE100-airlow.wav
Artificial ventilator	Nellcor, Puritan Benett LP6	Apnea	High	Beep	2800	85.6	LP6.wav
Artificial ventilator	Pulmonetic Systems, LTV 1000	Apnea	High	Beep	2865	80.9	LTV.wav
Artificial ventilator	Respironics, BiPAP Synchrony	Apnea	High	Pulses	2600	70.5	BiPAPHSout.wav
Monitoring system	Colin Medical Technology, NX BP-88	Apnea	High	Pulses	1100	70.8	NX-BP-88-high.wav

Table 5. Part I Answers (alarm sound)

		Year of experience																				
		Less than 3 yr					Less than 10 yr					More than 10 yr										
Sound	Subject ID	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	n1	Recognition rate %
a		a	a	a	a	a	a	a	a	a	a	x	a	a	a	a	a	a	a	a	18	94
b		b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	b	19	100
c		c	c	c	c	c	c	c	c	c	c	e	e	c	c	c	c	c	c	c	17	89
d		d	d	x	d	x	e	d	d	d	d	f	x	x	e	d	d	d	d	d	12	63
e		e	e	e	e	e	d	e	e	e	e	c	f	c	d	e	e	e	e	e	14	73
f		f	f	f	f	f	f	f	f	f	f	d	c	f	f	f	f	f	f	f	17	89
g		m	l	m	j	g	k	i	j	j	h	x	h	h	j	j	i	j	g	g	3	15
h		h	h	h	i	h	i	j	x	g	g	x	i	g	h	l	j	h	i	i	6	31
i		g	g	k	k	x	j	g	x	h	j	x	x	j	i	h	m	m	l	h	1	5
j		k	m	i	h	x	g	k	x	l	k	x	x	k	l	k	g	i	h	j	1	5
k		j	j	l	g	x	l	l	l	k	i	x	x	m	m	g	l	l	k	l	2	10
l		l	i	g	l	m	m	m	m	i	l	i	g	l	g	m	h	g	m	k	4	21
m		i	k	x	m	m	h	h	x	m	m	x	x	c	k	i	k	k	j	m	5	26
	n2	8	7	6	8	6	4	6	6	8	8	1	2	5	6	6	6	7	8	9	119	48
Identification rate %		61	53	46	61	46	30	46	46	61	61	7	15	38	46	46	46	53	61	69	48	

n1 – number of correct answers for each sound, n2 — number of correct answers for each subject. x = no answer.

Table 6. Part II Answers (priority)

Sound	Priority	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	n1	Recognition rate %
a	M	M	H	H	M	M	M	L	H	M	M	M	M	M	H	H	M	M	M	H	12	85
b	H	L	M	M	M	L	L	M	L	L	H	M	L	L	H	L	M	L	M	L	2	14
c	H	L	M	H	H	H	H	H	H	H	H	M	M	M	M	L	H	M	L	H	10	71
d	H	M	H	L	M	x	H	M	M	L	H	M	L	L	L	H	L	M	L	M	4	28
e	H	L	H	L	M	M	M	M	M	L	L	M	L	L	H	H	M	M	L	L	3	21
f	H	L	H	L	L	L	H	H	H	M	H	M	L	L	M	L	H	M	M	H	7	50
g	H	L	M	L	L	M	L	M	L	L	L	L	L	M	M	L	L	L	L	H	1	7
h	H	M	H	L	L	M	L	L	L	H	M	L	L	M	M	L	L	L	L	M	2	14
i	H	M	H	H	L	x	M	M	L	L	M	L	L	L	M	H	M	M	L	L	3	21
j	M	L	L	L	L	x	M	M	L	M	M	L	M	L	M	L	M	M	L	L	8	57
k	M	M	M	M	L	x	L	M	M	L	M	L	M	L	M	L	M	L	L	H	9	64
l	H	M	M	L	M	L	L	M	M	H	H	M	M	L	M	L	L	M	L	H	3	21
m	H	M	M	M	M	L	M	M	M	L	H	L	M	L	M	H	L	L	L	H	3	21
n2		3	7	3	2	2	5	4	3	3	9	1	3	1	4	4	5	2	1	5	67	27
Identification rate %		23	53	23	15	15	38	30	23	23	69	7	23	7	30	30	38	15	7	38	27	

n1 – number of correct answers for each sound, n2 — number of correct answers for each subject. H, M and l indicate a high. Medium and low priority *x* = no answer.

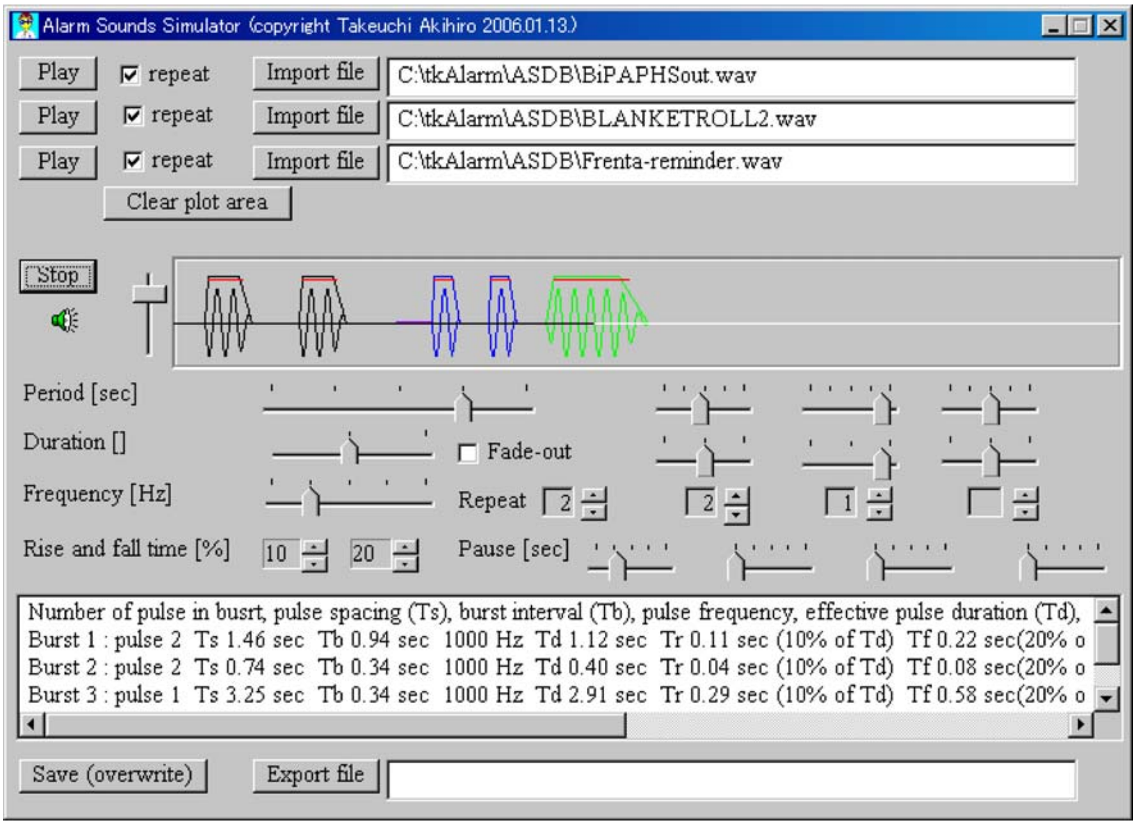


Fig. 3. A sample window of the alarm sound simulator. Three sound files, BiPAPHSout.wav, BLANKETROLL2.wav and Frenta-reminder.wav, were simultaneously set with a repeat mode in a player panel. A graphic profile of new alarm sound that is composed of two pluses, two narrow pulses and a wide pulse was drawn in the middle area. Sound characteristics recommended by the ISO format were automatically calculated and described in a lower edit box.

under the same auditory environment. This indicated that a medical device may need special impressive and distinct alarm sounds to be clearly recognizable. Although we are interested in the factors that influence alarm recognition, a future study must be done with a statistical analysis to confirm whether simple beep sounds may be suitable for alarms or not. The study will need to randomly play a large number of actual alarm sounds, as our database does. The overall recognition rate of sound priorities (27%) was lower than that of alarm sounds (48%). For sound ('b'), the recognition rate of the sound priority was 14%, whereas the recognition rate of the alarm sound itself (100%). The low recognition rate of the priority may be due to less attention given to the priority than the sound itself, such as an anesthesiologist's initial response might be to silence a louder alarm rather than to address the clinical procedure it indicates [11].

We investigated clinical engineers' discernment of alarm sound as they work closely with nurses and anesthesiologists in the ICU and/or the OR. The clinical engineers have intensive knowledge of medical devices, and setup and maintain most medical equipment in their hospitals. Although they are not especially trained in alarm sounds before the study, they are much more interested in alarm sounds than other medical staff who sometimes think of alarms as obstacles. Because of this investigation, the participants recognized that their knowledge and recognition of alarm sounds was insufficient and will change their attitudes toward better patient safety. This is one of our purposes in the present study. Although the accumulated knowledge and experience of skilled medical staff members could recognize many alarm sounds, beginners do not have many chances to train and hear alarm sounds except in actual alarm conditions. The training of troubleshooting in alarm conditions remains an undervalued factor in equipment management programs. Our database can assist in improving such conditions without any special setting up of equipment or additional cost. Medical devices should have functional buttons and/or a list that can be clicked on the monitor display to sound alarms in response to the user's requests.

The entire operating room environment must be considered not only individual devices [15]. Different functions may use the same alarm system with the same sound characteristics coined by a sound chip and the device housing. It has not been problematic in an individual device. However, there is a trend to integrate stand alone devices into multifunctional devices (e.g., monitoring systems, anesthesia machines, etc.). Alarms are not isolated events but parts of a whole workplace including display information. Though it might be difficult, it is needed to assess not only individual alarm but also the whole alarm system. The AlmSS can simultaneously play alarm sounds to simulate the actual sound environment of an operating room. The Windows Media Player, however, could not simultaneously play alarm sounds. We used the AlmSS to assess the ability of our medical staff to identify the alarm sources. The AlmSS is a design tool to interactively make new alarm sounds and to give a written description of each alarm sound under the ISO standards: characteristics of pulse, bursts, repetition rate, fundamental frequency, etc. Commercial musical sound editors are not suitable for designing alarm sounds. Even if medical staff might not require the AlmSS at present, they can create newer and more pleasing alarm sounds while considering other noisy alarm sounds and ask medical machine manufacturers to incorporate them into future models.

We have intended not to assert a correlation between years of experience and recognition of alarms and priorities but rather to present confusing situations qualitatively and quantitatively. Although our sound database is available on the Internet as a first step to improve situations, we should revise some of them and extend the database by adding new alarm sound data for many devices not currently used in our hospital. The database will be hyperlinked from any Internet forum in which functions of medical devices are discussed with medical manufactures. Although manufacturers typically only present alarm conditions and messages in their troubleshooting manuals at their websites, the alarm conditions listed should be linked to each actual alarm sound. We will make an online quiz to assess an individual's ability to identify each alarm source such as administrated in this study. Medical personnel and manufactures should recognize confusing situations and share the information of alarm sounds to improve the cacophony of the current noisy environment.

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