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Evaluation of medical alarm sounds

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ABSTRACT

EVALUATION OF MEDICAL ALARM SOUNDS

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Auditory alarms in medical equipments perform considerably below their optimal level. Concern has been expressed about the quality of medical alarms by a large number of researchers in recent years. A detailed literature survey on the medical alarm related problems has been carried out. Hospital visits were made to obtain real life information and data of alarm sounds in various type of monitors used in OR and ICU. A laboratory experiment has been conducted on selected melodic alarm sounds. These melodic alarm sounds are being implemented in medical equipments and the idea of design is proposed in ISO / IEC 60601-1-8. The tests were computer-administered and participated by 13 volunteers. Initially, volunteers were trained with the individual alarm sounds and the physiological cause of the alarm. Subsequently, they were tested for their learnability of the alarm sounds in the presence and absence of background noise and the results were compared. The presence of background noise did not have much effect on the correct identification rate. However, the confusion between the alarms sounds was significantly higher when background noise was present. Additionally the volunteers rated each alarm sound in terms of annoyance and urgency factor. Statistically significant correlation was found between the urgency rating and the annoyance rating of the alarm sounds.

EVALUATION OF MEDICAL ALARM SOUNDS

by
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LIST OF FIGURES

To my beloved family and friends

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TABLE OF CONTENTS

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

CHAPTER 1

INTRODUCTION

Patient monitoring is one of the central tasks in the hospital Operating Rooms (OR) and Intensive Care Units (ICU). With the advances in sensing technology, increasing number and variety of electronic monitors are being used in OR and ICU with the goal of providing more safer and efficient patient care [1, 2]. Most of these monitoring devices have audio and visual alarms to alert and inform either a patient's condition or a malfunction of the equipment. Due to the demanding situation, the information presented visually on a patient monitor will occasionally be missed entirely or reacted too slowly. For this reason, the auditory alarms are designed to alert physicians and nurses about critical conditions. Although the information provided by these monitors could be life saving, the proliferation in the total number of audio alerts, coupled with background noise from various medical equipments can create an environment which can be distracting and disconcerting to the care givers and patients [2]. Some of these equipments are equipped with auditory alarms which are so loud, insistent, or irritating that they are sometimes disabled by the attending physician [2].

The problems associated with the use of auditory warnings in the hospital environment are not substantially different from those found in other safety-critical and high mental workload environments such as the cockpit of the helicopter, or the control room of a nuclear power plant. It has been noted that, especially during an emergency situation, there are too many alerts coming at the same time; they are either too loud or inaudible; they are confusing, and there is often no consistent rationale associating the sounds with their meanings [3].

Each piece of medical equipment may have several different alert tones depending on what the problem is. Manufacturers tend to use their own preferred set of alert sounds. Similar sounding alarms can come from equipment with totally different functions because the same manufacturer makes them. Alternatively, equipment with same function, but from different manufacturers, can have completely different set of sounds. In an OR the number of different alert sounds may easily go over 30 and in ICU, monitors attached to each patient can produce 20 or more different alert sounds [1].

Many of the problems associated with auditory alerts in hospital environments are psychological in nature. A study by Patterson and Milroy [4] showed a person can only learn and remember 5 to 6 warning sounds. The alert sounds are confusing not only because they are too many of them, but also because many alert sounds use simple tones with variation of pitch of the tone to indicate the degree of criticality or type of physical or mechanical problems. As pitch judgement tends to be relative, rather than an absolute judgement, information is lost very quickly about the absolute values of pitches [5, 6].

There is lack of relationship between the urgency of a medical situation and the perceived urgency of the alarm sound, which signals that condition. The psycho-acoustic urgency of a warning might not be important if the meaning of the warning is already known. Unfortunately, it is not known in many instances [7]. Meredith and Edworthy [1] observed an ICU at Derriford Hospital, Plymouth. In the ICU, one of the food pumps used has an extremely loud, urgent sounding alarm. In contrast, the alarms of the ventilators were quieter. In terms of importance, the ventilator is more essential in maintaining the life support than the food pump. Experienced staff knows which sound is

more important, inexperienced staff may assume that the food pump alarm sound is more critical than the ventilator one.

Medical caregivers do not undergo training on the type of alarm sounds and their meaning. They generally learn the sounds while they attend the patient. Experienced staffs can, to an extent, differentiate the type of alarms and their meanings. Several researches [4, 8-12] have evaluated alarm sounds from most commonly used anesthesia machines. Most of the studies found that the experienced staffs performed better than non-experienced staffs, however, on an average even experienced staffs could not identify more than 30 percent of the alarm sounds. Many physicians and nurses work part time in different hospitals equipped with monitors from different manufacturer. Even in the same hospital, different OR may have monitors from different manufacturer. In the presence of many equipments with alert sounds, identification of the equipment which is producing the alert sound can be quite challenging for even the OR staffs who are familiar with OR equipments. A similar incident occurred during a visit to OR and ICU of UMDNJ, Newark (Details of the hospital visits will be provided in the next chapter). During an orthopedic surgery, the anesthetic staff took some time to identify the source of intermittent beeping sound. The alarm sounded from the Perfusion monitor. The perfusion monitor is connected to the Intravenous (IV) stand near the patient bed, at 30-35 inches above the ground level.

It has been widely recognized that auditory alarms in medical equipments perform considerably below their optimal level. Concern has been expressed about the quality of medical alarms by a large number of researchers in recent years. In a recent article, Edworthy and Hellier [13] summarize problems with medical alarms as:

"The main problems found with alarms are that they can often be too loud and shrill (because they are usually installed on a 'better-safe-than-sorry' logic) with the risk that they are turned off because they are so irritating, there are usually too many of them, they are often difficult to tell apart from one another and there are usually too many false alarms for the system to be trusted by the user. All of these factors contribute to alarms often being seen as getting in the way of a task rather than improving performance of that task."

Other safety critical areas, such as nuclear power plants or aircraft/helicopter cockpit have considerable use of monitoring and auditory alarming issues. But in those cases the subjects of monitoring and the functions they represent stay fixed from day to day. There has also been considerable effort by those industries to apply what is known about alarm design and alarm handling appropriately, and this has generally not been the case in clinical care [13]. In medical situation, the equipment used can vary for every patient and every procedure and thus the demands placed on alarm users are considerably greater. In an effort to improve the efficiency of these auditory alerts International Electronic Commission (IEC) and International Standards Organization (ISO) has proposed new standard on quality of the alert sounds and their functions. The following paragraph provides a brief overview of this development in standardization.

1.1 Recent Development in Medical Alarm Sound Standards

The important human factor characteristics of an efficient alarm design were known from long ago. Characteristics are: (1) easy to localize, (2) resistance to masking by other sounds, (3) allow communication, and (4) easy to learn and retain. Research initially concentrated on how alert sounds might be distinguished from background noise (audibility). Key work on this aspect of the sounds was conducted by Roy Patterson and his coworkers, who pioneered the systematic design of audible alarms in aviation [4, 14,

15]. He proposed systems of sounds based around combinations of 200 milliseconds (ms) tone bursts of varying intensity with rise/decay times of 20-30 ms containing four harmonics of a fundamental tone.

Later Kerr [16] proposed sound schemes related to six organ systems for medical equipment. Not all the systems were truly related to body organs, but rather represented six kinds of devices or monitors in which alarm conditions might lead to injury or death. These organ systems were oxygenation, ventilation, cardiovascular, temperature or energy deliver, drug delivery, and artificial circulation. There was also a 'general' sound, which could be used by any other device. Patterson's sounds did not conform to a specific rhythmic pattern; instead, each organ sound had its own rhythm, to confer additional distinctiveness.

Block [17] proposed an alternate set of 'organ system' sounds, in which each system was mapped onto a popular musical tune. It was believed that the common musical tones aid the listeners' learning ability of the alarm sound (learnability). For instance, the cardiovascular sound was to the tune of, 'I left my heart in San Francisco'. Television game shows and other games have made use of the fact that most people are able to distinguish and identify a large number of song tunes (melodies), often within just a few notes. With regard to the present standards, most manufacturers have opted to use a fixed pitch rather than these melodic sounds, perhaps because of the uncertainty about what 'tunes' could reasonably be used as an alternative. As a result, one of the main problems that the alarm standards wished to correct was not corrected: Similar devices might make different sounds, and different devices might make the same sound.

In the mid-1990s, Block and his co-workers [17] composed proprietary sounds for Datex-Ohmeda, a brand of anesthesia machine. These sounds were intended to convey a sense of urgency through the musical principle of the 'leading tone', that is, the listener's ear wants the sound to resolve to the High C above the last B. These sounds did serve their purpose in distinguishing the one brand of equipment from other brands, so that the alarm source could be more easily identified. These sounds are incorporated into the Datex-Ohmeda AS/3 monitors as one of three possible sets of high, medium, and low priority alarm sounds. Mondor and Finley [8] examined the perceived urgency of Datex-Ohmeda AS/3 monitors and found that these sounds indicated low in urgency. Chapter 2 explains several researches conducted on the existing anesthesia machine alarm sounds.

In 1994, Edworthy [18] introduced another concept. Edworthy suggested that more complex sounds could have patterns of pitch and pace that mapped the perceived urgency of the sound by the hearer to the urgency of the situation the sound was warning about (urgency mapping).

In 2000, a set of alarm sounds for use in anesthesia monitors was suggested by Block *et al.* [19] which was intended to have good performance in audibility, learnability and urgency mapping. It consists of 17 sounds coded to seven types of physiological measurement or instrumental situations. The physiological measurements / instrumental situations used (referents) were ventilation, perfusion, infusion of drugs / fluids, cardiac performance, oxygenation, power failure and temperature. Sounds keyed to these referents had two levels of urgency: medium priority and high priority. Three sounds were used for general warnings; these had low, medium and high priority.

In 2003, the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) [20] had convened a Joint Working Group (JWG) on Alarm signals and this standard was revised in the year 2005. These groups have drafted a collateral standard to IEC 60601: Medical electrical equipment - Part 1: General requirements for safety. This collateral standard is called IEC 60601-1-8; 'General requirements and guidelines for the application of alarms in medical electrical equipment'. The scope of this standard comprises all medical equipment; operating room, intensive care, hospital wards, clinics, and even home care. The standard accepted Block and his coworker's idea of alarm design; the alarm sound design that incorporates the audibility, ease of learnability and urgency mapping.

The ISO / IEC alarm standards provide for alarm signals that are prioritized according to high, medium, or low priority. A high-priority alarm is one that requires immediate operator action, a medium-priority alarm requires prompt operator action, and a low-priority alarm requires operator awareness. These standards specify a three-beat rhythm for medium-priority alarm sounds and a five-beat rhythm for high-priority alarm sounds. The medium-priority alarm is played once and repeats at 30 sec intervals. The high-priority alarm is played twice and repeats every 10 sec. The medium priority sound could be described musically as three half-notes. The high priority sound could be described as three quarter-notes, a quarter-rest, and two quarter-notes. These standards do not require specific pitches for these alarms, but rather specify a range of fundamental pitches (in the primary range for hearing) and require at least four harmonics (to promote hearing and direction location for the sound). The choice of pitches is left to the

manufacturer, though the United States standard requires the use of musical pitches (piano scale).

ISO/IEC 60601-1-8 type alarm sounds describes a method for design of audible alarms that do not simply alert, but that aid the operator in source identification and prioritization and that function to convey priority information. This standard has given the manufacturer an option to create melodic alarms that distinguish the physical or physiological system that each alarm represents [20]. Block and his co-workers idea of alarm design is proposed in IEC 60601-1-8.

1.2 Objectives and Goals of the Present Research

The objective of the study was to conduct a detailed literature survey on the medical alarm related problems. In addition to the literature survey, an observational study was conducted in two major hospitals and three surgeries were observed. The objective of the visits were to get acquainted with the type of monitors used in real life situations, record noise levels in OR, record auditory alerts, understand the major anesthetic equipments and also to interact with the anesthesiologists, OR and ICU staffs about the problems they face with alarm sounds. The goal of the literature survey and hospital visits was to compile the present state of art knowledge base pertaining to auditory alert design, which has been presented in the next chapter of this thesis.

Three qualities of an alert sound important for medical situation are learnability, urgency and annoyance that determine its effectiveness. However, these factors are based on human perception about these qualities of sound and these qualities can only be objectively measured from the perception of human subjects. Through my literature

survey, the author found that the newest set of alert sounds proposed by Block and incorporated in the latest IEC standard has been tested in laboratory by several researchers; however, in all of these laboratory experiments, the human subjects rated these alert sounds in isolation, i.e. without any background noise. In reality medical staffs listen to the alarm sounds with considerable background noise, which might affect the perception of sound quality measured in laboratory. Based on this intuition, the second objective was to conduct a laboratory experiment with the newest set of alert sounds to determine the effect of background noise on its Identification. The third objective of the study was to find the annoyance rate of these sounds and correlate it with its urgency rating. The experimental method and the results are presented from the chapter three onwards.

CHAPTER 2

BACKGROUND

This chapter presents the relevant background information needed for auditory alarm design for medical equipments. The discussion below concentrates on OR and ICU units, as medical alarms are most prevalent in these two places. Anesthesiologists and OR technicians are the prime users of these equipments, hence their work methods and interaction with monitors in OR have been elaborated. Problems with medical alarms have been already indicated in the introduction section. A more detailed analysis has been presented in this section based on the current research and hospital visits.

2.1 Anesthetist and the Work Environment

In early days, the anesthesia machine and monitoring systems displayed only visual information and the anesthetists had difficulty managing the patients and keeping track of the change in physiological parameters. So the auditory alarms were introduced in the anesthesia machines.

The Anesthesia Care Providers (ACP) are responsible for patients from the time they are taken from the preoperative area and brought into surgery until after completion of surgery when they are handed over to qualified recovery room personnel. The ACP use gases and intravenous drugs to induce a state of anesthesia in the patient and assumes responsibility for maintaining all the vital physiological functions that anesthesia suppresses. The ACP must monitor the patient's level of consciousness as well as his or her cardiovascular signs such as heart rate, blood pressure, and the blood oxygen level.

For those types of anesthesia that inhibit the patients ability to breathe spontaneously, ACPs control the ventilation (breathing) of the patient by either manually squeezing a bag attached to a face mask to push air into the patient's lungs or with a mechanical ventilator attached to the mask, which uses motor-driven mechanical bellows to accomplish the same task. The patient may also be intubated by placing a tube into the patient's trachea that leads to the lungs and attaching the tube to the bag or the ventilator. To be certain the patient is properly ventilated, the ACP monitor the measurements of various parameters associated with breathing such as respiration rate, inspired oxygen level, expired carbon dioxide level, airway pressures, and tidal (breath) volume.

Figure 2.1 demonstrates the layout of a typical operating room. During surgery ACP usually work at the patient's head with an anesthesia machine, which provides anesthetic gases and agents, the ventilator and additional patient monitoring systems are stacked above the anesthesia machine and comprise one side of the care provider's workspace. On the side of the ACP, a cart contains drug and other supplies. Quite often because of constraints of the physical environment, the anesthesia machine and monitoring systems are behind the ACP as he or she faces the patient.

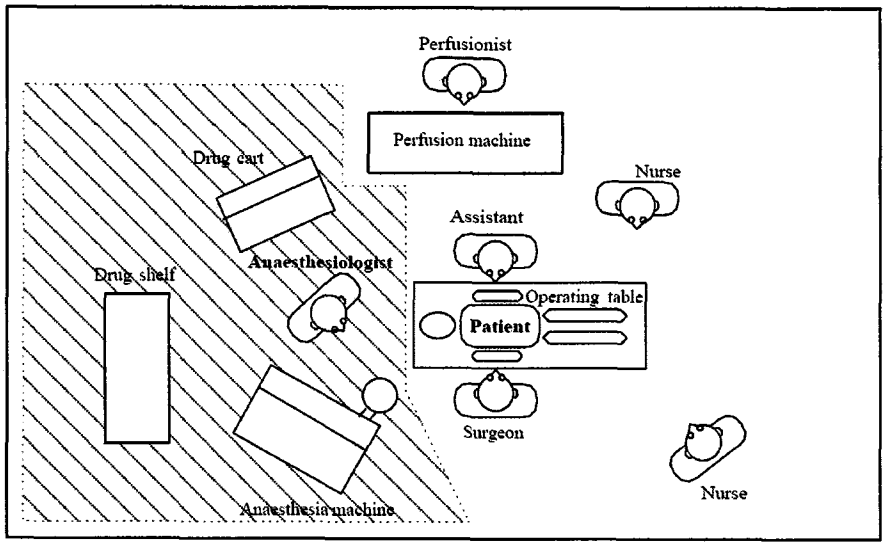

Figure 2.1 Typical Layout of an Operating Room. The perfusionist and perfusion machine is only for cardiac surgery. Source: Xiao. Y, "Interacting with complex work environment: A field study and a planning model". *Ph.D. thesis, University of Toronto, Toronto, Ontario, Canada.*, 1994.

While the patient is in the operating room, the ACP determines the normal range for the patient's vital signs from the patient's medical chart, and tracks deviations from that range. The ACP determines if the deviations are spontaneous, drug induced, or surgery induced. In addition the ACP notes in the anesthesia record: the drugs delivered, interventions performed and patient's vital signs throughout surgery.

2.2 Auditory Alarms

2.2.1 Number of Alarms

There are too many alarms in OR and ICU. The identification of each alarm and relating the alarm to its source is challenging. Different studies in the past have demonstrated that the staff cannot remember all of the alarms. One of the most cited pieces of psychological research demonstrates that our ability to remember pieces of unrelated information is limited to seven, plus or minus two [7]. This applies to remembering numbers, letters, words, sounds and many other items. The implication is that it should be difficult to learn

and retain the large numbers of alarms typical in many clinical settings. A study in a Canadian Hospital done by Momtahan *et al.* [7] demonstrated that of the nearly 50 alarms in the operating room and intensive care unit of a large Canadian hospital, fewer than half could be recognized by the clinical staff, even when they worked in this same area on a daily basis. Alarms were recognized correctly 39% of the time by nurses and 40% of the time by anesthetists and operating-room technicians.

In 1994 Alan J. Cropp [2] and his coworkers performed a study to determine whether the ICU staffs can identify the alarms with its sound alone. They recorded 33 (10 critical alarms) audio signals by using tape recorder in the ward. One hundred subjects listened to the tape for 10 seconds of audible and were given 10 seconds to write their response. The subjects identified only 50 percentage of the critical alarms and 40 percentage of the non critical alarms.

In a study done by Finley and Cohen [10] the anesthetists were tested to identify correctly the monitor alarm sounds. Only 33% of the time they identified the alarms correctly. Only two sounds were correctly identified by more than 50% of the participants, the oxygen supply failure alarm (84.4%) and the infusion pump (60.9%).

Loeb *et al.* [12] studied anesthesiologists recognition accuracy of OR alarms. Clinicians correctly identified the alarm source only 34% of the time and they concluded that anesthesiologists cannot reliably identify current OR alarms. Many of the alarms are spurious or false alarms due to patient movement, artifact, and problems with the biological sensor, algorithms or the patient-equipment contact. In another study by Lawless [21], he concluded that over 94% of alarm sounds may not be clinically important.

2.2.2 Alarms Loud, Irritating and Continuous

Manufacturers usually use 'loud is best' policy, so that their particular alarm is heard [1]. Patterson [14] believes that the alarms are installed with a 'better safe than sorry' policy by manufacturers. This results in auditory warnings that are 'too loud, too strident and too insistent'. Schmidt & Baysinger [22] also agree with this view, stating that most audible alarms are loud, produce continuous signals that cannot be adjusted or silenced, and that anesthetists waste their time trying to adjust or silence these alarms. They suggest that during an emergency it may be more effective to have a problem notified by a 'pleasant sound'. Hedley-Whyte [23] adds his support to the argument by stating that alarms are many times too loud, disturbing the surgeon and aggravating the rest of the staff.

2.2.3 Confusion of Alarms

When the alarms are acoustically similar but produced from different equipment, staff may waste valuable time by being unable to detect quickly enough which monitor is alarming. Some warnings consist of a continuous, high-pitched tone which most people cannot discriminate on an absolute basis [1]. Samuels [24] complains that it is often difficult to determine which monitor is sounding, and this can cause considerable anxiety to staff. At a visit to UMDNJ hospital, Newark a similar incident happened. An alarm sounded and the anesthetists wasted their time searching for the source of the alarm. The alarm sounded from the transfusion alarm which was kept near the patient bed with the IV stand. This type of situation can be easily avoided by designing alarms that can be easily identified. In an NHS Trust department [13], the King's Mill Centre Special Care Baby Unit, approximately 150 items of electrically powered medical equipment are functioning, 90% of which had at least one alarm sound. It is easy to imagine the

potential confusion caused by the simultaneous sounding of even a small number of these alarms, especially when one considers the pre-existing clinical pressures all clinical staff is under. It becomes obvious that alarms can, in some instances hinder as much as help.

2.2.4 False Alarms

Kesting *et al.* [25] found that an alarm sounds every 4.5 minutes and 75% are false alarms in a typical OR. False alarms may occur when the patient moves, during respiratory tract suction or when electrodes are loosened. False alarms can be threatening to patient care. The ICU and OR staff can become irritated to these false alarms due to the workload and number of patient monitoring or can be habituated to them, or can turn off the alarm system altogether [26]. Disabling the alarm can cause serious trouble, because the operator can easily miss important information if other staffs believe that the alarm is operating, this creates a false security to the patient. This situation might be worse than having no alarms.

McIntyre [11] conducted a survey regarding the auditory alarms and one of his question was to answer whether they have deactivated an alarm. 460 respondents out of a total of 789 (58%) responded 'Yes'. There were many reasons given for this course of action, which included the need for peace and quiet, the occurrence of too many false alarms during the task and the sheer unacceptability of the alarm itself.

A study conducted by Kesting and his coworkers [25] for analyzing the auditory alarms in the operating room shows that 75 percentage of all the alarms sounded were false alarms, not originated from changes in the physiological condition, only 3 percentage showed risks to the patients.

In 1997, Tsien and Fackler [27] after studying 298 monitored hours in a pediatric ICU in which 86% of a total of 2,942 alarms were found to be false-positive alarms, declared a "poor prognosis for existing monitors in the ICU". 64% of these alarms were related to pulse oximetry. Recent improvements in probes and improved motion resistant algorithms within the newer crop of pulse oximeters should hopefully do much to improve this dismal statistics.

There are too many alarms and most of the alarms are loud and continuous, which can be irritating and annoying for staff. Especially in the recovery room, patients after the surgery cannot tolerate the number of alarms. Most of the hospitals have 10-20 beds in a recovery room and the physiological parameters for each patient are monitored continuously. If there are too many false alarms at this time, patient cannot tolerate the noise at the recovery room especially when they are recovering from a long surgery.

2.2.5 Alarms and Type of Surgery

Seagull and Sanderson [28] observed anesthetists responses to audible alarms in the operating room. The study was conducted on four types of surgical procedures; (a) laparoscopy (closed abdominal surgery), (b) arthroscopic (closed) knee surgery, (c) cardiac bypass (open heart) surgery, and (d) intracranial (brain) surgery. The anesthetist's response to alarms across different phases of surgery was observed. Usually a surgery has the three phases; the induction, maintenance, and emergence. During these phases of surgery anesthetists go through different clinical issues and different uses of the anesthesia equipment.

The major goal of their study was to find evidence for different uses of alarms in different contexts in order to determine whether contextually based intelligent alarm

systems would be helpful or not. Four classes of questions were posed in order to determine the effective function of alarms during the surgery; (1) Do the frequency and kind of alarm, change across phases of a surgical procedure and whether the frequency of the alarm is further affected by the type of surgical procedure?, (2) Do anesthetists' responses to alarms differ across the induction, maintenance, and emergence phases of surgical procedures?, (3) Do responses to alarms differ across different kinds of procedures?, and (4) Do responses to the same alarm differ under different conditions?

During each procedure the following was observed: (a) principal surgical events and transitions between phases of anesthesia (e.g., start of emergence), (b) primary goal-directed activity and information-seeking by the anesthetist (e.g., check tubing), (c) major equipment states (e.g., alarms and warnings) and any actions initiated (e.g., drug delivery), (d) charting, recording, and calculations performed (e.g., estimates of doses and times), and (e) calibration and coordination of equipment (e.g., change alarm limits) and they also observed the time at which each happened. Seagull and Sanderson [28] also followed up with the anesthetists if they had any questions. During the study, observers noted down the time taken for each phase (induction, maintenance, and emergence) of the surgery. Seagull and Sanderson [28] believes that the alarms are not used simply to warn of problems but instead are used as tools with widely varying functions depending on type and phase of procedures. Based on the pilot study the alarms were classified base on the anesthetist's response to it as: 'Correction' or 'Change', 'Intended' or 'Expected', 'Ignore' or 'Nuisance' and 'Reminder' alarms. In 22 surgical procedures, they observed 132 episodes of audible alarms. Almost half the audible alarms, i.e., 48% are ignored, 33% are corrected, 12% act as reminders, and 6% are expected by the Certified

Registered Nurse Anesthetists (CRNA). From the study they concluded that the frequency of alarm changes according to the type of surgery and also it changed according to the phase of the surgery. Maintenance phase had the higher number of alarms.

Connecting the patient to the anesthesia machine and the monitoring devices at the beginning of each operation and disconnecting them at the end often causes alarms to sound when there are actually no problems. Technology cannot distinguish whether a patient has been disconnected purposefully, accidentally or whether a major change occurred in the monitored function. Contextual factors are used by anesthesia care providers to distinguish meaningful changes from a normal state of affairs. Sometimes a low heart rate is very worrisome and requires medication. At other times, for example, just after anesthesia is induced and before surgery starts- low heart rates are tolerated because the start of surgery will increase the heart rate even when a person is anesthetized. Furthermore, because no two patients are the same, there is uncertainty as to what constitutes normal and abnormal states.

2.2.6 Urgency Mapping

There is hardly any relation between the urgency of a medical situation and the perceived urgency of the alarm that signals that condition [29]. Finley and Cohen [10] analyzed the perceived urgency of the auditory signal and its correlation with the urgency of the corresponding clinical situation. They also analyzed the ability of the anesthesiologist to find the condition of the patient or the physiological change that was responsible for the alarm.

72 anesthetists were selected from a group of anesthesiologist who attended a national conference. Eight test datas were eliminated due to some hearing loss. The remaining 64 subjects were from 28 cities in Canada, the United States, Great Britain, and the West Indies. Warning signals from ten hospital monitors in an unused operating room were recorded and was played. A female voice announced the trial number prior to the warning signal. The duration of each of the ten presentations was 12 seconds with an inter-stimulus interval of five seconds. The time for each set of ten warnings was approximately 2.5 min. Testing took place in a relatively quiet area. The subjects were instructed to put on the headphones, start the tape, and rate each of the ten sounds on a scale from 1 (Not urgent at all) to 7 (Extremely urgent), without attempting to identify it. In the second test, subjects were informed that the same sounds would be played in a different order and that they were to identify which of nine possible monitors listed had produced each individual sound. Clinical urgency of the alarm was found from another study with 12 senior anesthetists (Canadian university department heads). The analysis indicated no significant correlation between the experts' assessment of the urgency of the situation and the anesthetists rating of the perceived urgency of the alarm.

Mondor and Findlay [8] examined numerous devices that are commonly found in any Operating Room (OR). They asked naive and experienced persons to rate different equipment auditory alarm signals according to their perceived sense of urgency. They found the perceived urgency of the alarm signal was not always congruent with the potential hazard and risk to the patient or healthcare provider

2.2.7 Melodic Alarms

The melodic alarms were proposed with the idea that the alarm should convey the meaning of the situation as soon as possible so that the clinicians can direct their attention effectively from the start rather than having to waste time seeking the source of the alarm [9].

Patterson [14] initially proposed melodic alarms for medical environments. The alarms consisted of sequence of notes of different pitches in a distinctive rhythm, and the urgency of the alarm would be indicated by playing the notes more rapidly. Kerr [16] proposed different approaches in alarm design: single all-purpose alarms, priority based alarms, equipment based alarms, risk based alarms, and risk and response based alarms. He proposed alarms for hypoxia, ventilator problems, cardiovascular problems, interruption to perfusion, drug administration problems, and thermal risk. Each alarm with a low and high level alarm state was distinguished by melodic changes.

The idea of melodic alarms was discussed by the ISO and CEN committees to consider including in the medical alarm standards focusing on six physiological parameters: oxygenation, ventilation, cardiovascular status, temperature, artificial perfusion, and drug administration (infusion). But the idea was criticized by Weinger [30].

Block[17] proposed alternative melodies for the six alarms. The melodies for each were based on popular tunes (e.g., 'love is blue' for oxygenation). Block conducted an informal study with 79 anesthetists and found that anesthetists could identify the alarms better when they had exposure to the alarm sound with their label. There was significant improvement on the second attempt, with 53% of anesthetists getting all six correct. He

pointed out the benefit of associating words with melodies for easier recognition and recall.

The ISO 9703-2 standard for auditory alarm signals on anesthesia and respiratory care equipment was released in 1994. But the standard did not recommend melodic alarms. The standard recommended rhythms for alarms at different levels of urgency. A medium priority alarms used three notes and a high priority alarms used three notes followed by two notes. The high priority alarm was played at a faster rate than the medium priority alarm.

Block and his colleagues [19] proposed another set of melodic alarm sounds that satisfied the ISO 9703-2 standard. They associated the alarms to the alarm sounds through the functioning of the medical equipment or physiological process itself. For example an oxygen alarm will sound when oxygen saturation falls from 100%. The melodic theme is a series of notes (OXYGEN-HI-P.WAV). All alarms were in the key of C major and had the same timbre. Table 2.1 shows the melodic alarm proposed by Block *et al.*

Table 2.1 Description of Melodic Alarm Proposed by Block *et al.* [19].

Auditory Alarm Category	**Medium Priority Alarm (Mnemonic)**	**High Priority Alarm (Mnemonic and other information)**
General	C4 C4 C4	C4 C4 C4 - C4 C4 (Fixed pitch; traditional (usual) 9703 sound)
Oxygen	C5 B4 A4 (OX-Y-GEN)	C5 B4 A4 - G4 F4 (OX-Y-GEN A-LARM; slowly falling pitches; top of a major scale; falling pitch of an oximeter)
Ventilation	C4 A4 F4 (VEN-TI-LATE; RISE AND FALL)	C4 A4 F4 - A4 F4 (VEN-TI-LA-TI-ON;VEN-TI-LATE A-LARM; RISE AND FALL - AND FALL)
Cardiovascular	C4 E4 G4 (CAR-DI-AC)	C4 E4 G4 - G4 C5 (CAR-DI-AC A-LARM Trumpet call; call to arms; major chord)
Temperature	C4 D4 E4 (TEM-P'RA-TURE)	C4 D4 E4 - F4 G4 (TEM-P'RA-TURE A-LARM; slowly rising pitches; bottom of a major scale; related to slow increase in energy or (usually) temperature)
Drug delivery	C5 D4 G4 (IN-FUS-ION)	C5 D4 G4 - C5 D4 (IN-FUS-ION A-LARM; Jazz chord (inverted 9th); drops of an infusion falling and 'splashing' back up)
Perfusion	C4 F#4 C4 (PER-FU-SION)	C4 F#4 C4 - C4 F#4 (PER-FU-SION A-LARM
Power failure	C5 C4 C4 (POW-ER FAIL) (GO-ING DOWN)	C5 C4 C4 - C5 C4 (POW-ER GO ^ ING DOWN; falling pitch as when the power has run down on an old Victrola)
Low priority alarm	E4 C4 (low priority) (IN-FO; MESS-AGE; ding-dong; doorbell or hostess call)	

Source: Block F.E., Rouse J.D, Hakala M, Thompson C.L. A proposed new set of alarm sounds which satisfy standards and rationale to encode source information. Journal of clinical monitoring and computing, vol. 16, pp. 541-546, 2000.

2.2.8 Evaluation of Effectiveness of Melodic Alarms

Williams and Beatty [31] trained 21 non-clinicians to identify the Block *et al.,* alarms using just the mnemonics (e.g., 'CAR-DI-AC A-LARM') and without further supporting information that explains the mapping of the melody to the alarm source. Participants learned the alarms in a first session and then returned a week later for further learning and test. During testing, identification accuracy ranged from 10% for the medium-priority ventilator alarm to 61% for the medium- priority oxygen alarm. Accuracy for the simple general alarms was 85% and 90% for medium and high-priority alarms respectively. Participants rated all the high-priority alarms as sounding significantly more urgent than the medium-priority alarms, and they rated the medium-level alarms as sounding more urgent than the low-priority alarm. There was systematic confusion between alarms, such as between Cardiovascular and Temperature, Infusion and Ventilation, Perfusion and Ventilation, Perfusion and Infusion, Cardiovascular and Oxygen.

In 2006, Sanderson and his team [32] analyzed the learnability and discriminability of the IEC 60601-1-8 type alarms. Thirty-three non-anesthetist participants learned the high-priority and medium-priority alarms over two sessions of practice, with or without mnemonics suggested in the standard. The learning criterion set by Sanderson and his team was that the participant should be able to identify all the alarms correctly on two successive occasions, when alarms were presented in random order. On Day 1, only 44% of the mnemonic participants and 27% of the non-mnemonics participants reached the learning criterion. On Day 2, only 28% of the mnemonic and 27% of the non-mnemonic participants reached the criterion. Sanderson and his team found that responses to medium-priority alarms were faster and more accurate than high-

priority alarms. They found both mnemonic and non-mnemonic participants having confusion with cardiovascular and temperature, infusion and ventilation alarms. Sanderson *et al.* analyzed the influence of musical training on the participants. They found that the musically trained (just one year of formal training) participants were able to identify the alarms accurately than non trained participants. The participants also rated the related urgency of the medium and high-priority alarms on a 7 point scale. Ratings for the high-priority alarms was 4.8 and medium-priority alarms was 3.1. Musically trained participants rated high priority alarms as more urgent than non-trained participants.

In 2007, Lacherez [33] and his coworkers explored how accurately and quickly nurses can identify melodic medical equipment alarms when no mnemonics are used, when alarms may overlap, and when concurrent tasks are performed. Nurses learning were poor and were no better than the learning of non nurses under the same conditions in the Sanderson *et al.* study. Only 14% of the nurses reached the learning criterion on Day 2. Musically trained nurses performed better than the non-trained nurses. Nurses showed the previously noted confusions between alarms. Strong mutual confusions were seen between Cardiovascular and Temperature, and between Perfusion and Power failure. In addition, in a series of one-way confusions, Temperature was mistaken for Oxygen, Infusion for Perfusion and Ventilation for Temperature and Infusion. Overlapping alarms were exceptionally difficult to identify.

2.3 Continuous Auditory Monitoring

Almost all the research on monitoring systems focuses on visual displays or auditory alarms [34] and tends to ignore the potential for continuous monitoring displays to inform

rather than to alert. Continuous monitoring may reduce demands on the anesthesiologist's visual attention, allowing patient variables to be monitored in the background; eyes-free monitoring. Naturally occurring continuous sound will often move into focal awareness if it signals an unexpected state [35]. These properties, coupled with the success of variable-tone pulse oximetry in clinical monitoring, have encouraged several research groups to investigate patient monitoring using sonification or earcons [36].

2.3.1 Sonification

Sonifications have been developed for patient monitoring using various combinations of Heart Rate, Oxygen, Blood Pressure, Respiratory Rate, Ventilation, and End Tidal Volume, among other variables. Fitch and Kramer [37] showed that nonanesthesiologist participants could identify physiological events better when the events were sonified than when displayed in a traditional visual form. Using a similar sonification, Seagull *et al.* [28] found that nonanesthesiologists detected changes in patient variables faster with a visual display, but a time-shared manual-tracking task was performed most accurately when patient variables were sonified only. In a later study, Loeb and Fitch [38] reported that anesthesiologists could identify six anesthesia events effectively with a two-stream sonification of the above six variables; Heart Rate, Oxygen, Blood Pressure, Respiratory Rate, Ventilation, and End Tidal Volume. Events were detected faster with a combined visual and sonified display but more accurately with a visual display than with a sonified display.

Watson and Sanderson [39] developed a respiratory sonification that combines information about Respiratory Rate (RR), inspired and expired ratio, Ventilation (VT), and End Tidal CO_2 ($ETCO_2$) into one sound stream. Flow of gas is represented by

relatively pure tones distinguishing inspiration and expiration, rather than the breath-like sound used by other researchers. Using the body simulation and 11 anesthesiologist participants, Watson and Sanderson showed that anesthesiologists can monitor RR, VT, and $ETCO_2$ as accurately with the respiratory sonification as they can monitor HR and oxygen saturation (SpO_2) with variable-tone pulse oximetry. In a series of 10-min scenarios based on reported incidents, the anesthesiologists identified clinical conditions as accurately with auditory monitoring (pulse oximetry plus respiratory sonification) as they did with visual monitoring. Moreover, when the anesthesiologists performed an unrelated time-shared task (simple arithmetic) in parallel with patient monitoring, they monitored the simulated patient as effectively with auditory monitoring as with visual monitoring, but with auditory monitoring they performed the time-shared task better.

There are several potential disadvantages of continuous monitoring. One of the potential disadvantage is that the anesthetists may habituate to abnormal pitch and volume levels or may fail to notice slow changes if no auditory standard for comparison is provided, making visual backup or other cues essential. Second, anesthetists may become over-reliant on continuous signals (compared with other less salient or more intermittent clinical signs) and may over-treat as a consequence. Third, although pilot studies suggest that respiratory sonification may be less vulnerable to interference from music than from having to perform time-shared tasks, there may be some acoustic masking from other ambient noise. Fourth, without the symbolic labels available in a visual display, participants may misinterpret the mapping of vital signs to the different auditory dimensions of a sonification. And finally, a continuous auditory display may not always be well tolerated by clinicians, coworkers, or patients [39]. Despite the success of

the pulse oximetry tone, anesthesiologists are concerned about the potential annoyance of another sound in the OR.

2.3.2 Earcons and Auditory Icons

Earcons are auditory displays that encode data or system states into short tunes [40]. Otherwise it is a short discrete sounds or sound patterns that carry information about the status of a variable [41]. Auditory icons have immediate natural associations with a state or object. Unlike sonification, earcons and auditory icons still require the listeners' focused attention and therefore recommended less for the surgical team [40].

2.4 Noise Level in OR and ICU

Murthy *et al.* [42] measured the noise levels in operating rooms and found that the average operating room noise level is 77.32 dB(A). In a study conducted by Kracht *et al.* [43] in John Hopkins Hospital, they found the noise levels in operating rooms throughout Johns Hopkins Hospital during different surgical procedures. In total, 38 operating room noise levels were measured. Operations in all branches of medicine were examined including neurology, cardiology, orthopedics, urology and plastic surgery. Surgeries performed on both adult and pediatric patients were monitored. Table 2.2 demonstrates noise level at different surgeries.

Table 2.2 Noise Level during Different Surgery Procedure

Division	No. of Surgeries	Ave. Level dB(A)	Range dB(A)
Pediatric Orthopedic	2	57.9	56.8 – 58.7
Gynecological	2	60.2	54.4 – 63.4
Thoracic	4	62.9	61.6 – 63.6
Gastrointestinal	9	62.9	54.9 - 68.8
Cardiology	10	63.4	57.1 – 67.8
Urology	11	63.6	55.6 – 67.0
Pediatric Urology	2	64.1	64.0 – 64.1
Neurosurgery	8	64.5	60.2 – 67.3
Otoloaryngology	4	64.8	53.0 – 66.4
Pediatric Plastic	4	65.2	62.2 – 68.4
Orthopedic	19	66.3	56.7 – 70.3
Plastic	3	66.9	58.8 – 68.9

Source: J.M. Kracht, I.J. Busch-Vishniac, and J.E. West, "Noise in the operating rooms of Johns Hopkins Hospital," *Journal of the Acoustical Society of America*, vol. 121, no. 5, pp. 2673-2680, 2007.

The ICU is often a noisy environment. Bentley *et al.* [44] measured the noise in the ICU using a decibel (dB (A)) recording system. They found the average level was 53 dB during the day and 42.5 dB at night. To compare, typical results for a living room during the day are 40 to 50 dB and for a quiet bedroom at night are 20 to 30 dB. Figure 2.2 shows the ICU noise level.

The alarm design should take into consideration the amount of noise level and design the alarms that can be heard without being masked by the noise in OR and ICU. Simply increasing the alarm sound intensity will only increase the annoyance factor of the alarm.

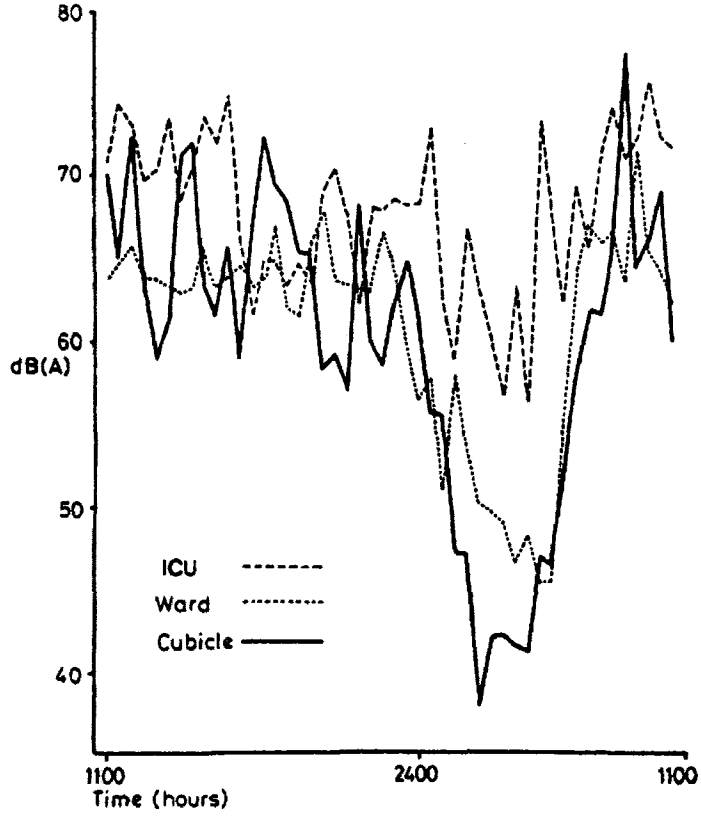

Figure 2.2 Noise pollution levels measured in ICU.

2.5 Different Standards Developed

The British Standards Institute (BSI), the Committee European the Normalization (CEN), the International Electrotechnical Commission (IEC) and the International Standardization Organization (ISO) are developing standards on auditory warnings for various aspects of patient care. The standards recommend that the auditory warnings must vary in their degree of urgency depending upon the medical urgency of the situation and they must sound the same from hospital to hospital.

ISO recommendations set out clear limits for the design of medium and high priority alarms, including such factors as the dominant frequency of an alarm, the number of individual pulses that may comprise a 'burst', and the repetition rate of both the pulses

within a burst and of the bursts themselves. The ISO recommendations also include suggestions that the auditory characteristics of low priority alarms and signals intended to provide information should generally be quite different from the medium and high priority alarms. In addition, these two types of alarms should be nonintrusive and nonstartling, with amplitudes no more than that of the corresponding medium priority alarm, and onset and offset times of at least 40 ms.

One of the principal motivations in establishing these recommendations for the design of auditory warning signals appears to have been "to have a pattern which is instantly recognizable to the trained respondent, but which will not usually evince anxiety in others" [20]. Thus, the guidelines established by ISO are intended to facilitate the generation of alarms that are clear and easy to interpret. The recommendations also speak of another important element of alarm design; namely, the importance of tailoring the acoustic properties of each alarm to the urgency of the triggering situation. In particular, the ISO standards include a suggestion that the time between pulses within a burst and the most prominent frequency component of a pulse be modulated to exert some control over the sense of urgency induced in a listener by the alarm. This recommendation is consistent with research indicating that basic auditory features such as pitch, loudness, and repetition rate may have a dramatic influence on the perception of the urgency of an alarm. Thus, a sound with a high pitch or a rapid repetition rate will be perceived as more urgent than a sound with a lower pitch or repetition rate.

Auditory alarm signals should be encoded as to the urgency of the problem and also encoded by type of device. In this way, all heart rate alarms, no matter which manufacturer has supplied the device, will sound the same.

2.6 Hospital Visits

To explore the use of electronic monitoring equipment within the context of anesthetic practice and to analyze the real time situation in the Operating Room (OR) and the ICU, we visited the Sacred Heart Hospital in Allentown, PA and UMDNJ Hospital in Newark, NJ.

From the observation at two of the many operating rooms at Sacred Heart Hospital, we understood that the hospital is equipped with anesthesia machines manufactured by different manufacturers. Each machine is equipped with different auditory alarm sounds. One of the operating room is equipped with Draeger Apollo anesthesia machine and the other with Narkomed anesthesia machine. The operating room we visited at UMDNJ hospital had a Datex-Ohmeda anesthesia machine.

At both the hospital we recorded the real time operating room noise using an Olympus DS40 digital voice recorder. The data were collected at three different surgery procedures; angioplasty, orthopedic surgery and a tumor removal surgery. We observed angioplasty surgery in Sacred Heart Hospital and orthopedic and tumor removal surgery in UMDNJ Hospital. At UMDNJ Hospital we also collected the noise level at the Intensive Care Unit.

During the orthopedic surgery at UMDNJ, some of the alarms were easily masked by the noise created by the drilling machines and the other sounds created while cutting the bone. Even though the patient was connected to the electronic monitoring equipments the anesthesia staff kept looking at the patient for any unexpected change in any physiological parameter (for example; touching the patient face to sense his/her body temperature, and to see whether the patient appear pale etc.)

In one of the ICU at UMDNJ, there were 18 beds in one room. Each patient bed had one electronic monitor to monitor patient heart rate, Blood Pressure, and Respiratory rate etc. There were two nurse stations and both the nurse stations had monitors which showed all of the patient data. Monitors at both patient and nurse station had visual and auditory display. At the nurse station, all the 18 patient data displayed in the same monitor. Both the patient and nurse station monitors alarmed when there is any change in physiological parameter in any patient. There were times when more than 10 alarms sounded simultaneously (from different patient monitors). In ICU, the patients were recovering from a long surgery and the noise level in that room would definitely affect their mental health.

Different monitoring equipment images were taken during the hospital visits. Please refer Appendix A for the images.

CHAPTER 3

LABORATORY EXPERIMENT

The effectiveness of the newly proposed melodic alarm sounds proposed by Block *et al.* [19] that conform to the revised ISO / IEC 60601-1-8 standard has been evaluated by several researchers [31-33]. Study results demonstrated some improvement over the commonly used tonal sounds in terms of identification and confusion between different body system alarms. However, none of the previous laboratory studies evaluated these sounds in the presence of background noise which is normally present in OR and ICU. According to the objectives mentioned in the introduction, this section describes a laboratory experiment performed to determine the effect of background noise on identification and confusion characteristics of the selected melodic alarm sounds. Additionally, perceived urgency and annoyance characteristics of the individual alarm sounds were tested in this laboratory experiment.

Four sets of physiological monitor (Cardiac, Temperature, Ventilation, and Oxygen) alarm sounds proposed by Block and his coworkers [19] were used for the study, because these alarms are most common in the OR and ICU [45]. Each monitor alarm has a high and a medium priority alarm sound. This makes a total of eight sounds. These alarm sounds are all 5-tone (High priority version) or 3-tone (Medium priority version) melodies. These alarm sounds were obtained from http://www.usyd.edu.au/anaes/alarms/ [46]. The sounds are eight bit 22 kHz mono uncompressed files in windows wav format. The operating room noise was recorded from UMDNJ Hospital, Newark and Sacred Heart Hospital, Allentown using an Olympus DS

40 digital voice recorder. Electrical noise was removed from sampled OR and ICU noise by the noise removal function of Audacity 1.3 software [47]. The alarm sounds were incorporated into the sampled operating room noise using the mixing 2 track function in Audacity 1.3. The combined sounds were presented with WAV on maximum volume and main volume control at level three from the lowest setting.

The test was conducted at the Safety Laboratory in the Industrial Department at New Jersey Institute of Technology. The experiment was administered using computer program written in Visual C++. The alarm sounds were presented to the participants using a Dell Inspiron 1501 computer with AMD Sempron™ processor. Participants took the test in a quiet environment. Before the start of experiment, the experimenter checked whether the sound level was clear and comfortable for the participant. Each study lasted about an hour.

The study was approved by Institutional Review Board (IRB) of New Jersey Institute of Technology. IRB approval and Consent form can be found in Appendix B.

3.1 Volunteers

13 volunteers were students of New Jersey Institute of Technology who were mostly undergraduate and graduate students. There were 4 female and 9 male participants. Participation was voluntary and participants provided written informed consent approved by IRB. None of the participants had hearing impairment. They received $10 for their participation.

3.2 Session 1 - Learning the Sounds

A typical sounds learning session screen is shown in figure 3.1. The software provided an interface for the participant to play eight selected alarm sounds. Each alarm was played five times to the volunteer. Name of the alarms is written next to each sound button and also each alarm sound was played following a male voice pronouncing the name of the alarm sound. At the end of the learning session, the volunteers were asked to take an identification test. A preliminary identification test screen is shown in figure 3.2. The volunteers who scored 50% in the preliminary identification test proceeded to the session 2; urgency and annoyance rating and session 3; identification with and without noise. Volunteers who did not score 50% both the times did only session 2; urgency and annoyance rating.

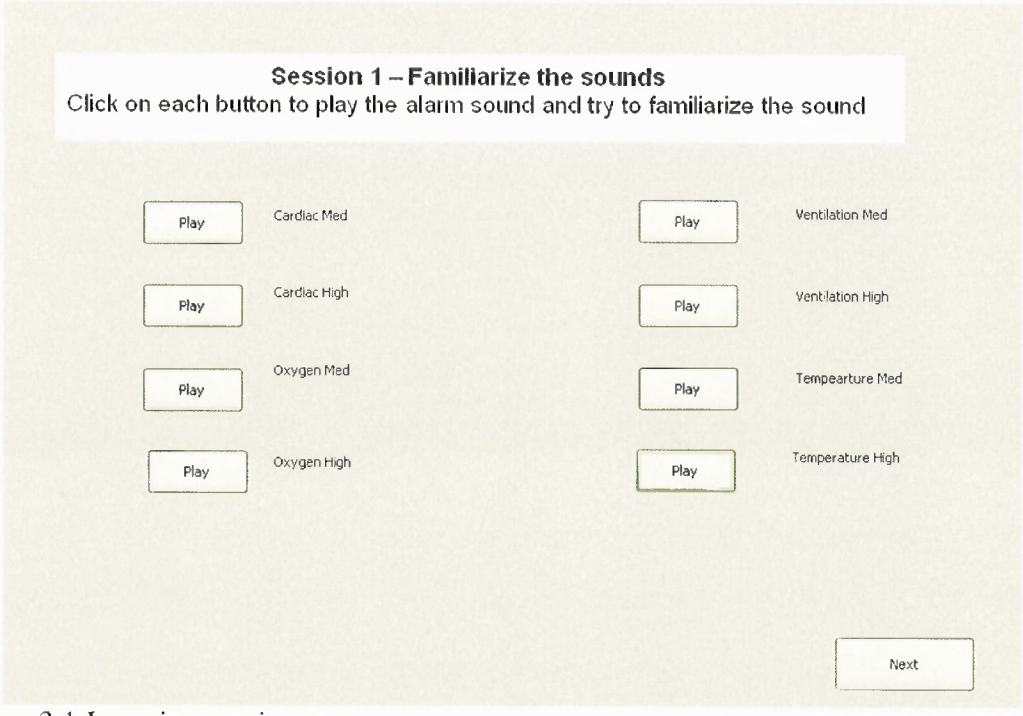

Figure 3.1 Learning session.

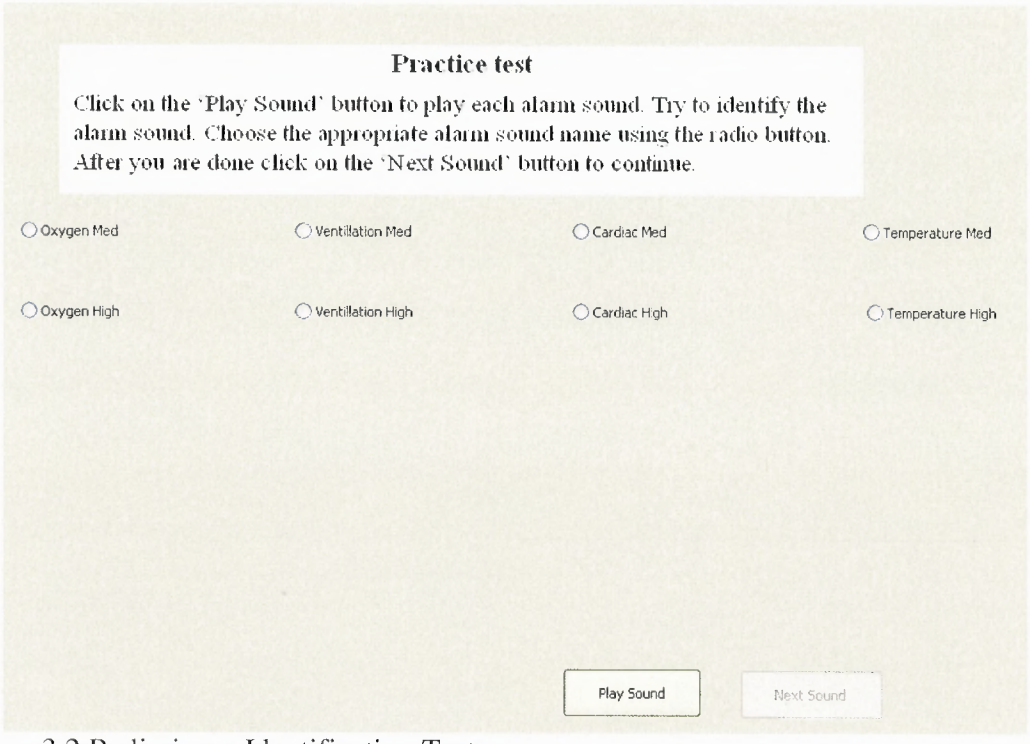

Figure 3.2 Preliminary Identification Test.

3.3 Session 2 -Urgency and Test Annoyance

The annoyance and urgency test followed after the learning session. Volunteers were asked to rate each alarm sound on its urgency and annoyance on a scale of 7 from (1) not at all and (7) critical using radio buttons. The urgency and annoyance test screen is shown in figure 3.3. Upon pressing the play button, the participant heard the alarm sound. The alarm sounds were played randomly and each alarm was played three times that makes a total of 24 alarm sounds. Software allowed the participant to listen to the alarm again if they wished to. But they could not proceed to the next sound without giving their ratings.

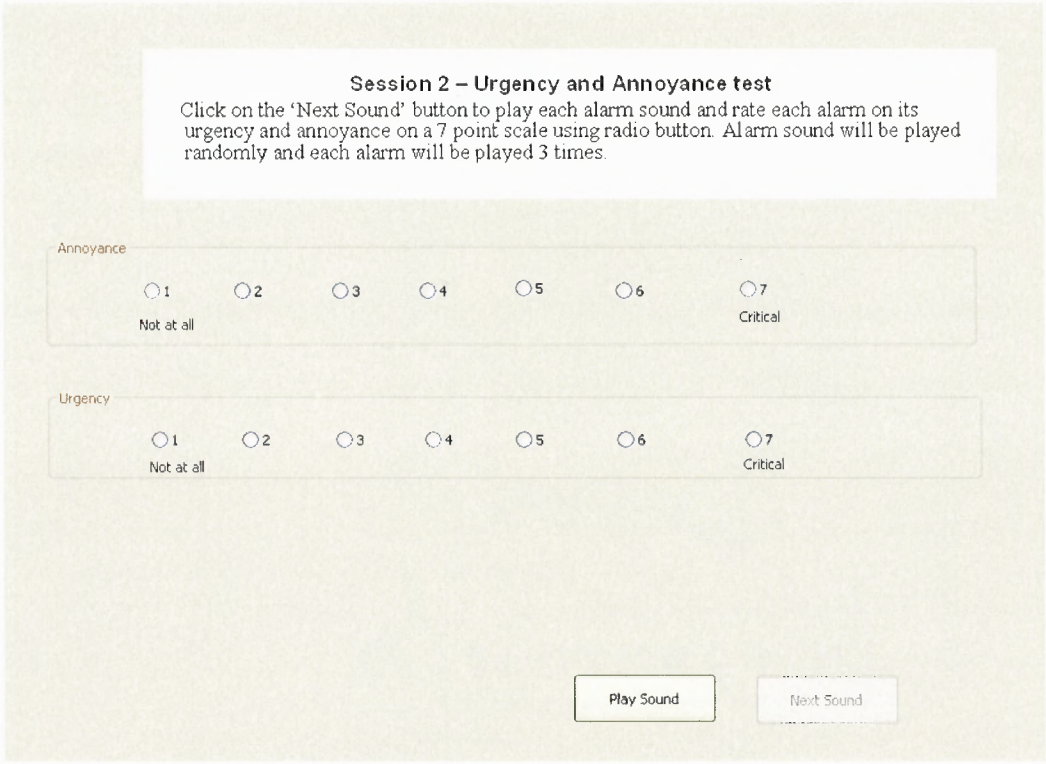

Figure 3.3 Urgency and Annoyance Test.

Computer software stored the response of each subject in a file. The file contained name of the alarm sound and the corresponding rating given by the subject. The data can be found in Appendix C

3.4 Session 3 - Identifying the Alarm Sound

The participants who scored 50% correctly during the preliminary Identification test proceeded to this Identification and Confusion test. This test was given in two parts; (1) with noise background and (2) with out noise background. Eight alarm sounds were played randomly. Each alarm was played three times in random order that makes a total of 24 alarm sounds. The same was repeated for alarms with background noise. The identification test without and with noise are represented in figure 3.4 and 3.5 respectively. Volunteers listened to the alarm and chose the alarm sound from the list of

alarm sound names using the radio buttons. Software allowed the participant to listen to the alarm again if they wished to. But they could not proceed to the next sound without answering.

Computer software stored the response of each subject in a file. The file contained name of the alarm sound and the corresponding response given by the subject. The data can be found in Appendix C

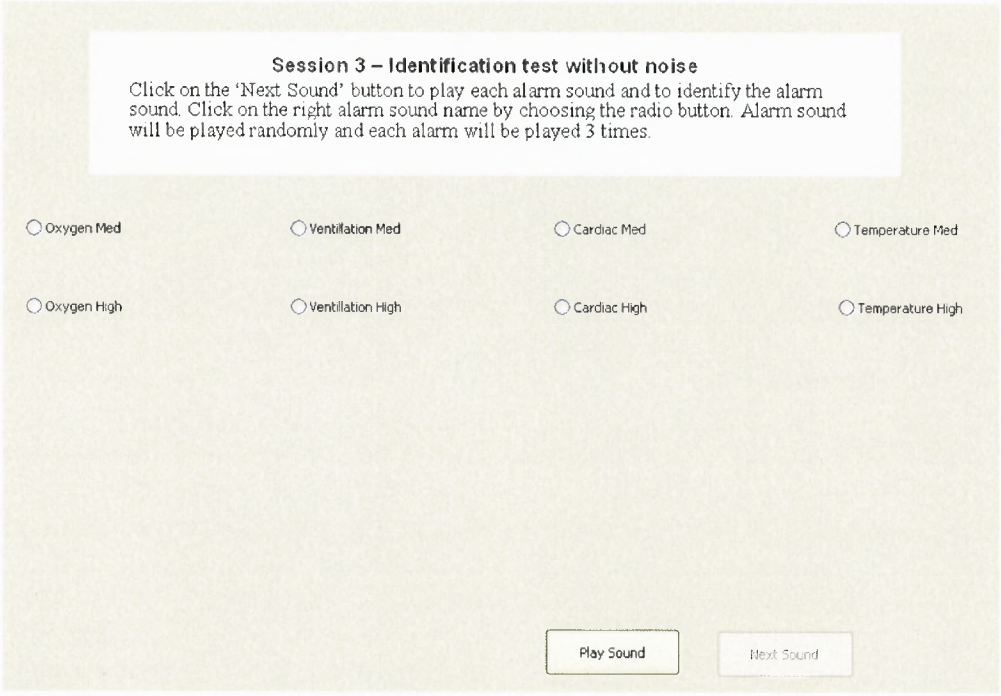

Figure 3.4 Identification Test without Noise.

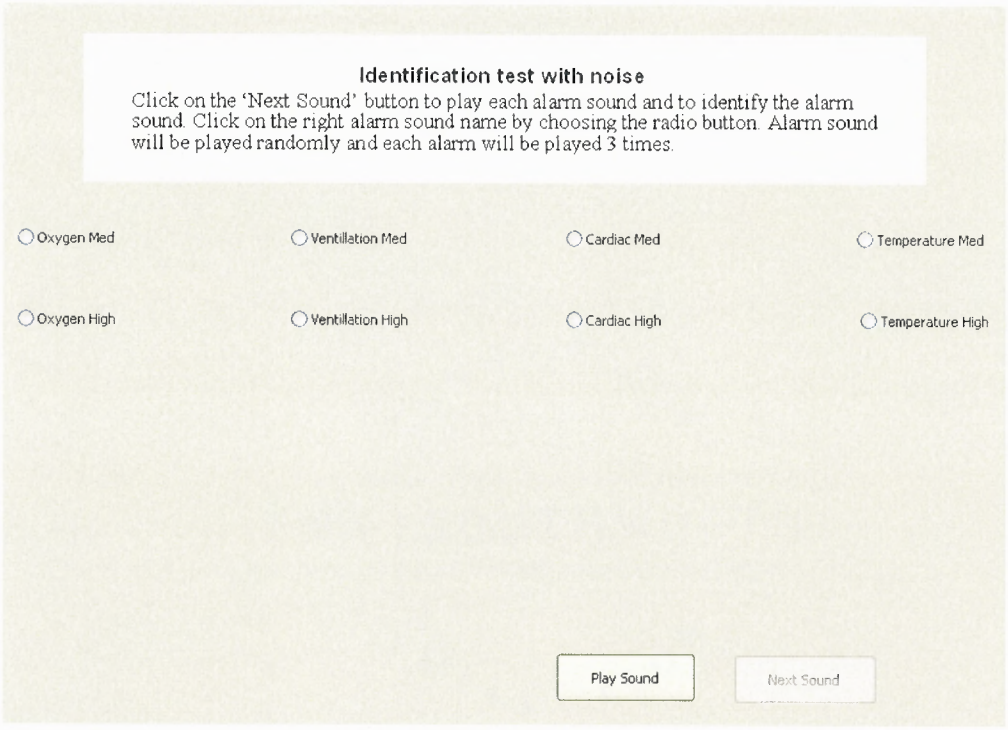

Figure 3.5 Identification with Noise.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Preliminary Identification Test

The overall correct identification rate was 48.56 %. Out of 13 volunteers only 6 (46.1%) passed the criterion to take session 3 test; identification with and without noise. The volunteers who scored 50% in the preliminary identification tests proceeded to the session 2; urgency and annoyance rating and session 3; identification with and without noise. Volunteers who did not score 50% did only session 2; urgency and annoyance rating. The identification score can be seen in Appendix C.

4.2 Urgency and Annoyance Rating

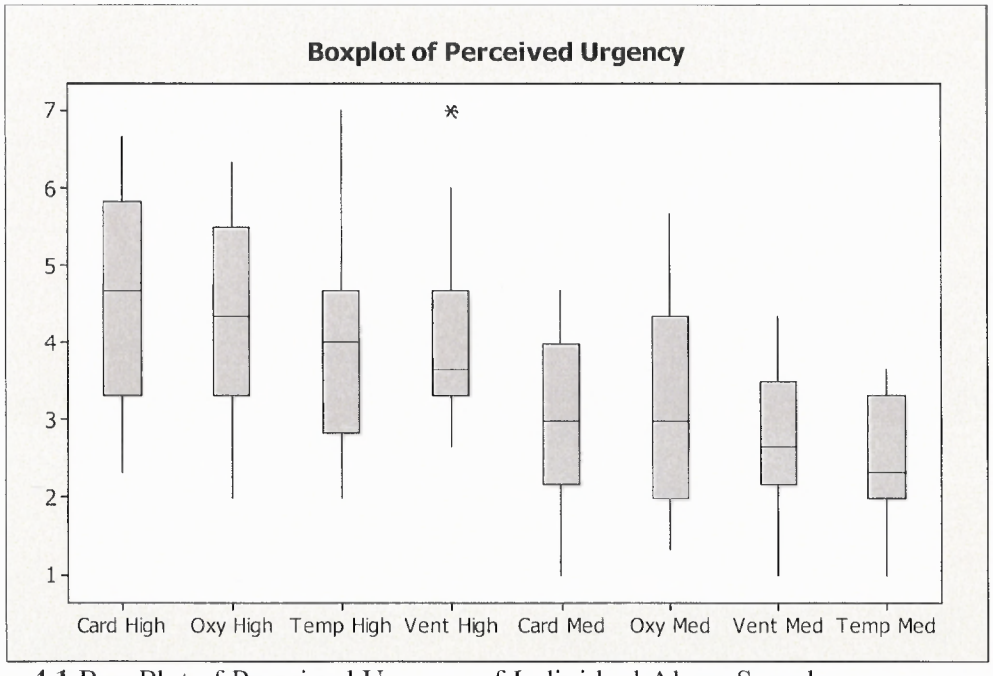

Figure 4.1 Box Plot of Perceived Urgency of Individual Alarm Sounds.

Figure 4.1 shows box plot drawn using MINITAB, of the perceived urgency scores for the 8 alarm sounds given by all volunteers. The solid box shows the inter-

quartile range of the data; the line across the box represents the median data value. '*' represents the outlier; case with value between 1.5 and 3 times the inter-quartile range. The median value does not show a normal distribution. Because of the nonnormality of the data, each alarm sound was given a mean rank on a scale 1 to 8 and a graph is drawn using MINITAB in a descending mean rank order. Figure 4.2 shows the mean rank arranged in descending order. High Priority alarm sounds have mean ranks from 5.342 to 6.6 and medium priority sounds have mean ranks from 2.076 to 3.88. 'Cardiac High' alarm sound has the highest mean rank of 6.61. The box plot and the mean rank clearly show that the urgency rating of the higher priority alarms was greater than the medium priority alarms.

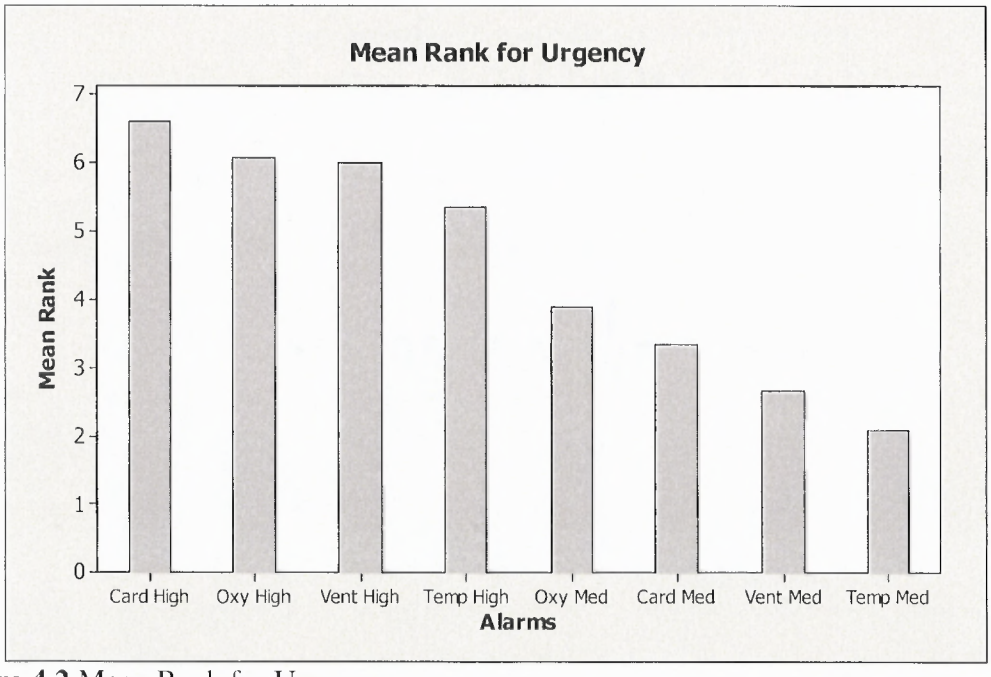

Figure 4.2 Mean Rank for Urgency.

Figure 4.3 shows box plot of the perceived annoyance scores for the 8 alarm sounds given by the volunteers. Figure 4.4 shows the mean rank arranged in descending order. High Priority alarm sounds have mean ranks from 4.19 to 5.30 and medium

priority sounds have mean ranks from 3.38 to 5.346. 'Cardiac Med' alarm sound has the highest mean rank of 5.346.

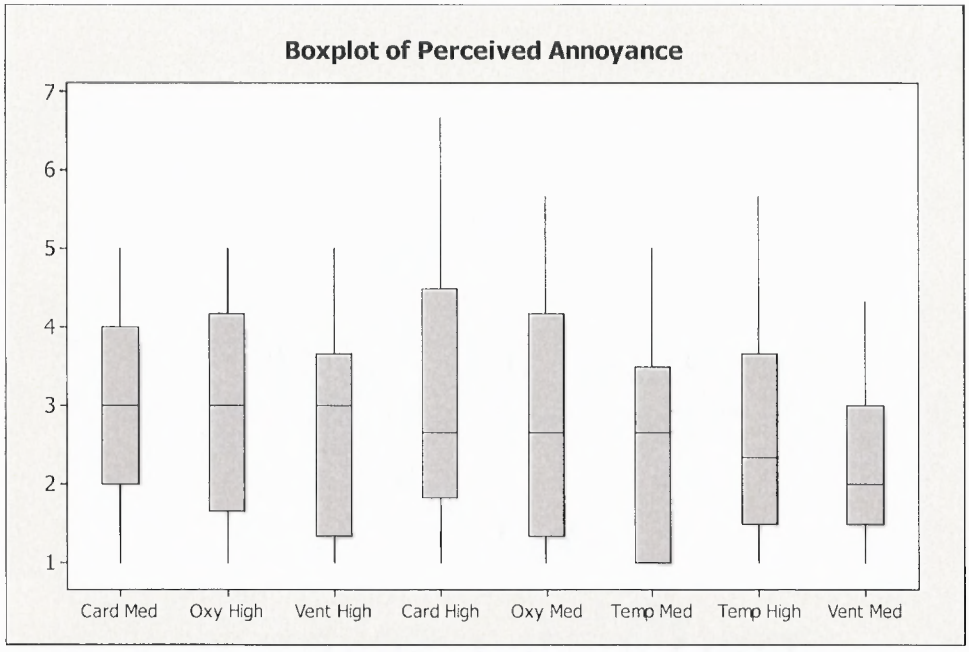

Figure 4.3 Box Plot of Perceived Urgency of Individual Alarm Sounds.

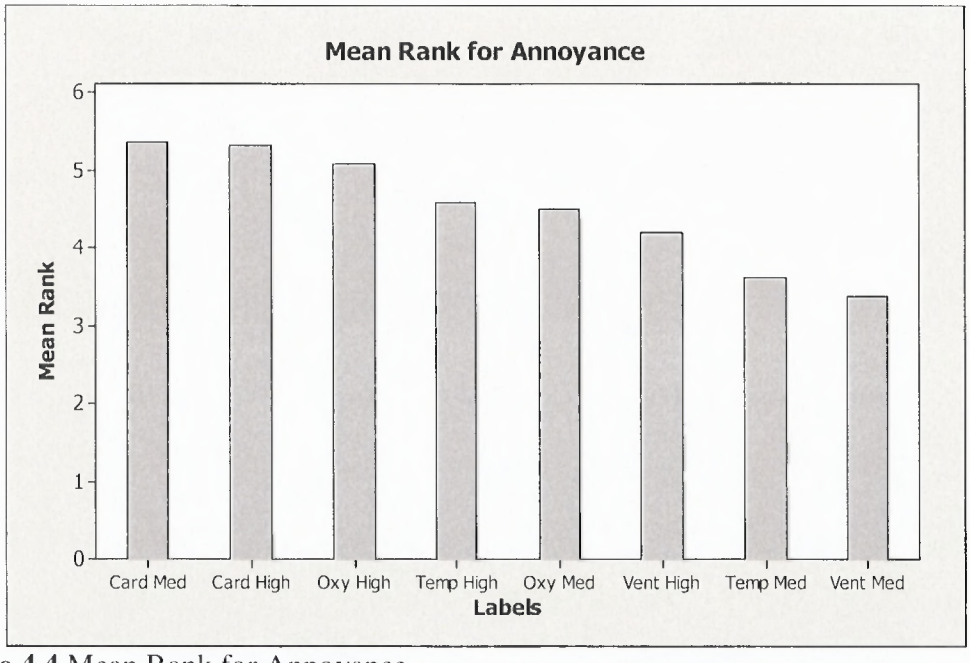

Figure 4.4 Mean Rank for Annoyance.

Pearson's correlation coefficient was calculated using MINITAB for the medium and high priority groups alarms together and was observed to be r = 0.614, with a probability p = 0.106. Within the high priority group the correlation coefficient was significant, r = 0.995, with probability p = 0.005 but within the medium priority correlation was not significant r = 0.631, p = 0.369.

4.3 Identification with and without Noise

Identification and confusion matrix in a study done by Williams and Beatty [31] on the Block *et al.* [19] alarm sounds is provided in table 4.1. The sounds actually played to the volunteers are shown on the second column of the matrix and as they were identified along the in third row of the matrix. The sounds are grouped according to priority. Correctly identified sounds lie along the diagonal of the matrices (shown in dark grey boxes). Cells containing confused sounds (i.e. given sound A the volunteers identify sound B) are shaded light grey.

Some identification must be the result of accident; error due to inattentiveness or momentary lapse in concentration, thus it is logical to ask what number of 'hits' on a cell in the matrix is really statistically significant. Williams and Beatty [31] conducted a Monte Carlo simulation of 20 iterations of the test for 20 participants where all responses were random indicated that the chance of getting 5 in any cell was p = 0.01, 4 in any cell was p = 0.03, 3 in any cell p = 0.01. They choose a statistically significant confusion to be $p<0.05$, that is more than 5 in any cell.

Table 4.1 Identification & Confusion Matrix-Study Conducted by Williams & Beatty[31]

Identification Data with Noise										
		Medium Priority Alarms				High Priority Alarms				**Correct Identification Rate (%)**
Sound Played \ Sound Perceived		Ventmed	Oxymed	Cardmed	Tempmed	Venthigh	Oxyhigh	Cardhigh	Temphigh	
Medium Priority Alarms	Ventmed	**4**	9	1	1	0	0	0	0	10.30
	Oxymed	6	**25**	4	1	0	0	0	0	61.00
	Cardmed	8	7	**14**	10	0	0	0	0	33.00
	Tempmed	1	7	9	**20**	0	0	1	0	45.50
High Priority Alarms	Venthigh	0	0	0	0	**9**	4	2	3	22.00
	Oxyhigh	0	0	0	0	1	**21**	2	6	52.50
	Cardhigh	0	0	0	0	9	2	**18**	8	42.90
	Temphigh	0	1	0	1	2	7	7	**17**	41.50
									Mean	**38.59**

A similar approach was taken in this study. A Monte Carlo simulation of 20 iterations of the test for 6 participants where all responses were random indicated that the chance of getting 6 in any cell was $p = 0.01$, 5 in any cell was $p = 0.04$, 4 in any cell $p = 0.10$. For the purposes of this study, cells needed to contain five or more hits to be considered statistically significant ($p < 0.05$).

Table 4.2 and 4.3 represents the confusion matrix and identification rate with and without noise respectively. The overall correct identification rate with noise was 39.58%. The correct identification rate without noise was 40.28%. All the datas can be seen in Appendix C.

Table 4.2 Identification and Confusion Matrix (with Noise)

Identification Data with Noise										
		Medium Priority Alarms				High Priority Alarms				Correct Identification Rate (%)
Sound Played \ Sound Perceived		Ventmed	Oxymed	Cardmed	Tempmed	Venthigh	Oxyhigh	Cardhigh	Temphigh	
Medium Priority Alarms	Ventmed	**6**	2	4	6	0	0	0	0	**33.33**
	Oxymed	7	**6**	3	2	0	0	0	0	**33.33**
	Cardmed	1	3	**11**	3	0	0	0	0	**61.11**
	Tempmed	7	1	3	**7**	0	0	0	0	**38.89**
High Priority Alarms	Venthigh	1	0	0	0	**5**	4	5	3	**27.78**
	Oxyhigh	1	0	0	0	6	**8**	3	0	**44.44**
	Cardhigh	0	0	0	0	6	0	**7**	5	**38.89**
	Temphigh	0	0	0	1	3	4	3	**7**	**38.89**
								Mean		**39.58**

Table 4.3 Identification and Confusion Matrix (without Noise)

Identification Data without Noise										
		Medium Priority Alarms				High Priority Alarms				Correct Identification Rate (%)
Sound Played \ Sound Perceived		Ventmed	Oxymed	Cardmed	Tempmed	Venthigh	Oxyhigh	Cardhigh	Temphigh	
Medium Priority Alarms	Ventmed	**7**	2	2	7	0	0	0	0	**38.89**
	Oxymed	7	**5**	6	0	0	0	0	0	**27.78**
	Cardmed	1	2	**12**	3	0	0	0	0	**66.67**
	Tempmed	0	0	2	**7**	0	0	0	0	**38.89**
High Priority Alarms	Venthigh	0	0	0	0	**7**	3	4	4	**38.89**
	Oxyhigh	1	0	0	0	3	**8**	3	3	**44.44**
	Cardhigh	0	0	0	0	4	4	**8**	2	**44.44**
	Temphigh	0	0	0	0	4	1	0	**4**	**22.22**
								Mean		**40.28**

Even though the correct identification rate with noise was not significantly different from identification rate without noise, the confusion between alarms in the presence of noise is more prominent.

CHAPTER 5

CONCLUSION AND FUTURE WORK

The study provided an up-to-date literature survey on auditory medical alarms related problems in OR and ICU. The major problems identified were: there are too many auditory alarms; there is confusion between alarm sounds, and alarm sounds loud and irritating.

A laboratory experiment was conducted on selected newly proposed alarm sounds in accordance with IEC 60601-1-8 standard. 13 volunteers were tested for the identification rate of alarm sound in the presence and absence of noise. This study for the first time evaluated the alarm sounds in the presence of noise in OR. The identification rate of the alarm did not change between the noise and no noise study, but the confusion between alarms increased in the presence of background noise.

The laboratory experiment also evaluated the urgency and annoyance rating of the alarm sounds. The urgency rating of the higher priority alarms was greater than the medium priority alarms.

A statistically significant correlation was noted between the annoyance and urgency rating of higher priority sounds. This implies that with increase of urgency the annoyance will also increase. This is a commonly seen phenomenon in various auditory alarms.

Future Work: (1) Due to the limitation of time, only 13 participants could be tested. Larger number of subjects could improve the statistical significance of the results. (2) The study can also take into account the noise effect on urgency and annoyance

rating. (3) Block *et al.* [19] has proposed similar type alarm design for Infusion, Perfusion, Power failure and general alarms. A future study can take into account all of these sounds and evaluate their performance in the presence of background noise.

APPENDIX A

ANESTHESIA MACHINES

Figure B.1 represents anesthesia machine in Sacred Heart Hospital, Allentown. This is comparatively older machine manufactured by Narkomed. Figure B.2 to B.4 provides close up views of different visual monitors of this machine. Figure B.5 is a close up view of a newer model anesthesia machine manufactured by Draeger Apollo seen in Sacred Heart Hospital, Allentown

Figure B.1 An Older Anesthesia Machine Manufactured by Narkomed.

Figure B.2 Monitor Used to Monitor the Gas Inflow and Outflow.

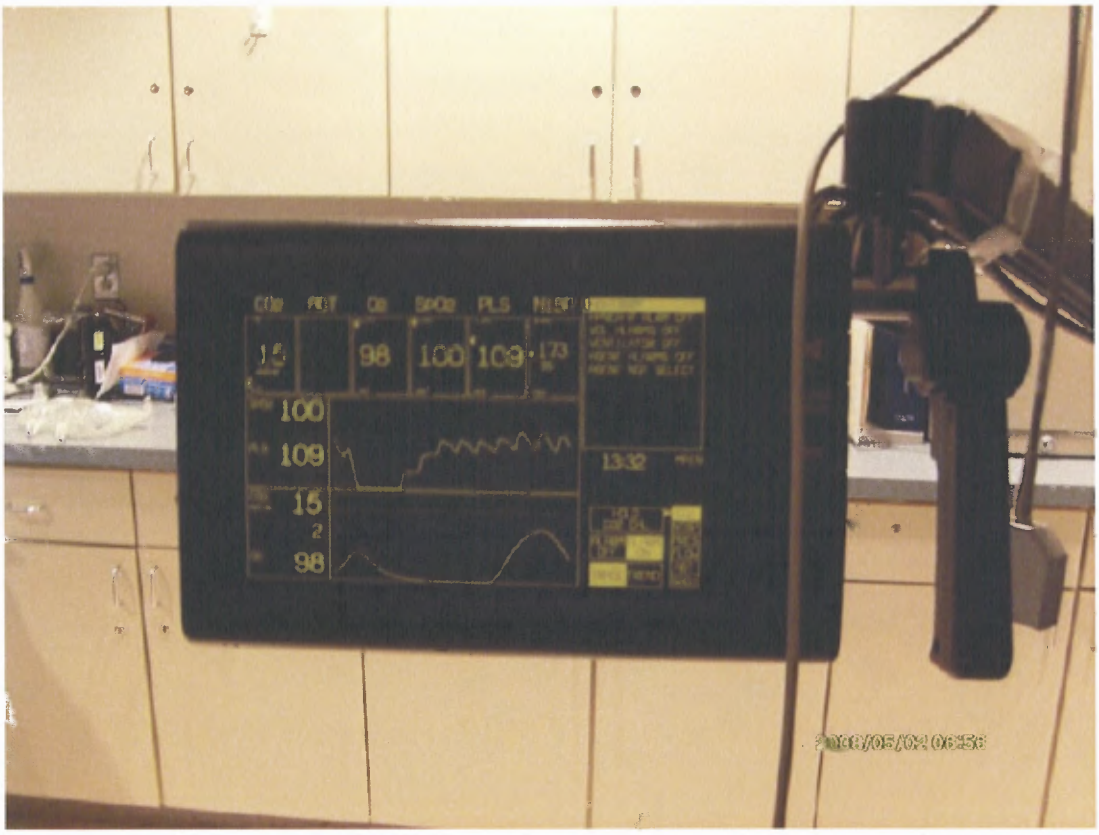

Figure B.3 Patient Physiological Parameter Monitor (CO_2, SpO_2, and Blood Pressure, etc.).

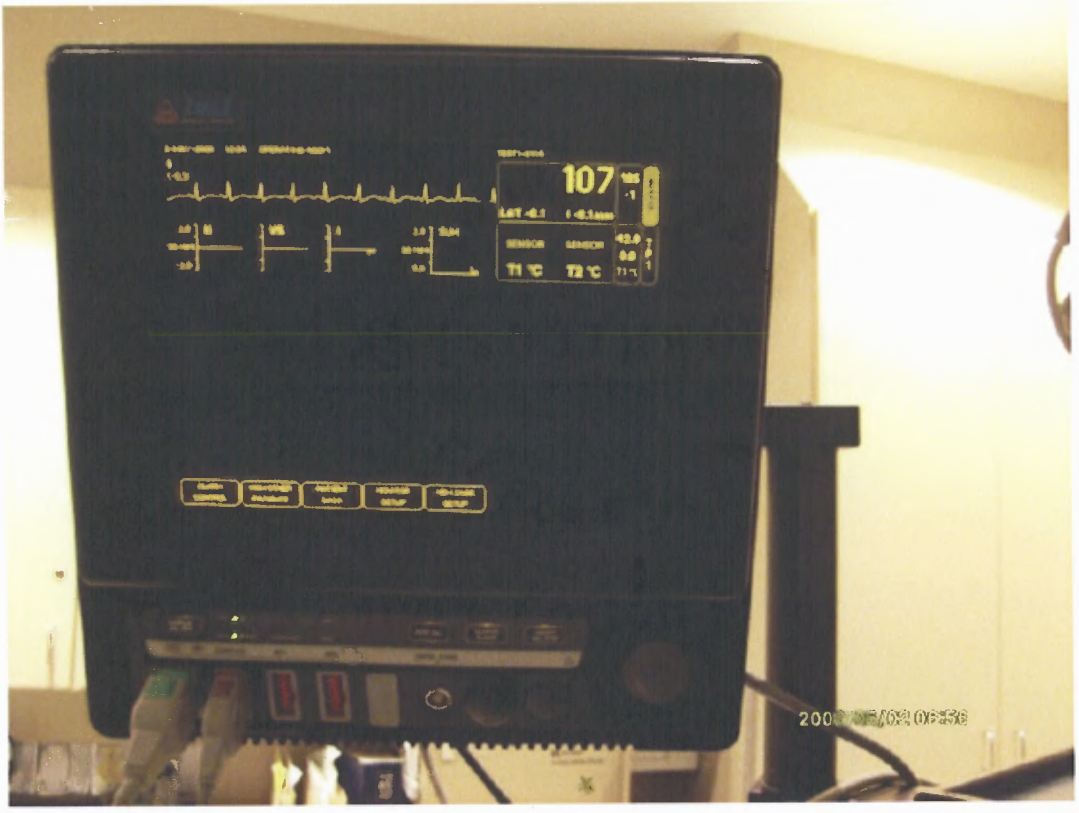

Figure B.4 Patient Physiological Parameter Monitor (Pulse rate, ECG, and Temperature, etc.).

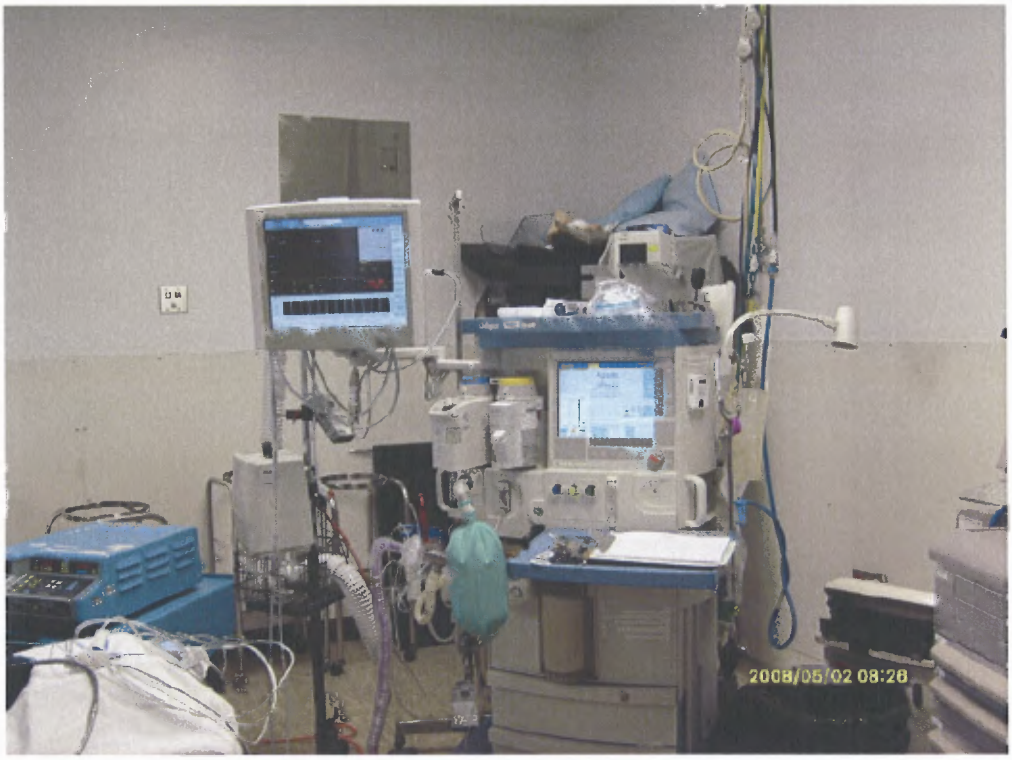

Figure B.5 Drager Apollo anesthesia machine in one of the Operating Room in Sacred Heart hospital, Allentown.

APPENDIX B

IRB INFORMATION

NJIT NEW JERSEY INSTITUTE OF TECHNOLOGY

Institutional Review Board: HHS FWA 00003246
Notice of Approval
IRB Protocol Number: F98-08

Principal Investigators:	Arijit Sengupta and Elizabha Phillip Department of Engineering Technology
Title:	Evaluation of the Operating Room Alarm Sounds
Performance Site(s):	NJIT
Sponsor Protocol Number (if applicable):	
Type of Review:	FULL [X] EXPEDITED [ ]
Type of Approval:	NEW [X] RENEWAL [ ] REVISION [ ]
Approval Date:	December 1, 2008
Expiration Date:	November 30, 2009

1. ADVERSE EVENTS: Any adverse event(s) or unexpected event(s) that occur in conjunction with this study must be reported to the IRB Office immediately (973) 642-7616.

2. RENEWAL: Approval is valid until the expiration date on the protocol. You are required to apply to the IRB for a renewal prior to your expiration date for as long as the study is active. It is your responsibility to ensure that you submit the renewal in a timely manner.

3. CONSENT: All subjects must receive a copy of the consent form as submitted. Signed consent forms must be kept on file with the principal investigator.

4. SUBJECTS: Number of subjects approved: 30.

5. The investigator(s) did not participate in the review, discussion, or vote of this protocol.

6. APPROVAL IS GRANTED ON THE CONDITION THAT ANY DEVIATION FROM THE PROTOCOL WILL BE SUBMITTED, IN WRITING, TO THE IRB FOR SEPARATE REVIEW AND APPROVAL.

Dawn Hall Apgar

Dawn Hall Apgar, PhD, LSW, ACSW, Chair IRB December 1, 2008

NEW JERSEY INSTITUTE OF TECHNOLOGY
323 MARTIN LUTHER KING BLVD.
NEWARK, NJ 07102

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

TITLE OF STUDY: Evaluation of the operating room alarm sounds

RESEARCH STUDY:
I,_____, have been asked to participate in a research study under the direction of Dr. Anjit K. Sengupta. Other professional persons who work with them as study staff may assist to act for them.

PURPOSE:

The purpose of the study is to compare the ISO/IEC 60601-1-8 and the existing operating room alarms for its perceived urgency, perceived annoyance and perceived identification.

DURATION:
My participation in this study will last for 1-2 hours.

PROCEDURES:
I have been told that, during the course of this study, the following will occur:

1. I will be asked to provide name, email address, phone number, and age.
2. I will be asked to wear a headphone.
3. I will be asked to listen to alarm sounds to familiarize the sound and the type of the sound.
4. I will be asked to rate the alarm sound in terms of urgency, annoyance and finally I will be asked to identify the sound

PARTICIPANTS:
I will be one of about 30 participants in this study.

EXCLUSIONS:
I will inform the researcher if I am not over the age of 18 or not under the age of 60 and/or I have any hearing disabilities

RISKS/DISCOMFORTS:
I have been told that the study described above may involve the following risks and/or discomforts:

The alarm is played in a continuous manner for 15 seconds only. The main volume control of the computer will be kept at level three from the lowest. The experimenter will check and make sure that the sound level is clear and comfortable for the participant. There also may be risks and discomforts that are not yet known.

I fully recognize that there are risks that I may be exposed to by volunteering in this study which are inherent in participating in any study. I understand that I am not covered by NJIT's insurance policy for any injury or loss I might sustain in the course of participating in the study.

CONFIDENTIALITY:
I understand confidential is not the same as anonymous. Confidential means that my name will not be disclosed if there exists a documented linkage between my identity and my responses as recorded in the research records. Every effort will be made to maintain the confidentiality of my study records. If the findings from the study are published, I will not be identified by name. My identity will remain confidential unless disclosure is required by law.

PAYMENT FOR PARTICIPATION:
I have been told that I will receive $10 compensation for my participation in this study.

RIGHT TO REFUSE OR WITHDRAW:
I understand that my participation is voluntary and I may refuse to participate, or may discontinue my participation at any time with no adverse consequence. I also understand that the investigator has the right to withdraw me from the study at any time.

INDIVIDUAL TO CONTACT:
If I have any questions about my treatment or research procedures, I understand that I should contact the principal investigator at:

Arijit K. Sengupta
Associate Professor
Department of Engineering Technology
Room # GITC 2517
NJIT, Newark, NJ 07102-1982
Tel: 973 642 7073
Email: sengupta@njit.edu

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Harrison, NJ 07029
Ph: 864 - 320 - 4487
Email: ep44@njit.edu

NJIT

Approved by the NJIT IRB on 12/1/08.
Modifications may not be made to this consent form without NJIT IRB approval.

If I have any addition questions about my rights as a research subject, I may contact:

Dawn Hall Apgar, PhD, IRB Chair
New Jersey Institute of Technology
323 Martin Luther King Boulevard
Newark, NJ 07102
(973) 642-7616
dawn.apgar@njit.edu

SIGNATURE OF PARTICIPANT

I have read this entire form, or it has been read to me, and I understand it completely. All of my questions regarding this form or this study have been answered to my complete satisfaction. I agree to participate in this research study.

Participant Name _____

Signature _____

Date _____

SIGNATURE OF READER/TRANSLATOR IF THE PARTICIPANT DOES NOT READ ENGLISH WELL (Only needed if English fluency is not an exclusion criteria)

The person who has signed above, _____, does not read English well. I read English well and am fluent in (name of the language) _____, a language the subject understands well. I have translated for the subject the entire content of this form. To the best of my knowledge, the participant understands the content of this form and has had an opportunity to ask questions regarding the consent form and the study, and these questions have been answered to the complete satisfaction of the participant (his/her parent/legal guardian).

Reader/Translator Name _____

Signature _____

Date _____

SIGNATURE OF INVESTIGATOR OR RESPONSIBLE INDIVIDUAL (Only required for consent forms of projects requiring full IRB approval)

To the best of my knowledge, the _____ participant, has understood the entire content of the above consent form, and comprehends the study. The participants and those of his/her parent/legal guardian have been accurately answered to his/her/their complete satisfaction.

Investigator's Name _____

Signature _____

Date _____

APPENDIX C

EXPERIMENT TEST DATA

Preliminary Identification Test Data

CARDIAC MEDIUM was played				CARDIAC HIGH was played			
Subject	Response 1	Response 2	Total Correct Response	Subject	Response 1	Response 2	Total Correct Response
Subject 1	Card Med	Card Med	2	Subject 1	Vent High	Oxy High	0
Subject 2	Card Med	Card Med	2	Subject 2	Card High	Card High	2
Subject 3	Card Med	Card Med	2	Subject 3	Card High	Card Med	1
Subject 4	Card Med	Vent Med	1	Subject 4	Oxy High	Card High	1
Subject 5	Temp Med	Temp Med	0	Subject 5	Card High	Card High	2
Subject 6	Temp Med	Oxy Med	0	Subject 6	Card High	Card High	2
Subject 7	Card Med	Oxy Med	1	Subject 7	Card High	Card High	2
Subject 8	Card Med	Temp Med	1	Subject 8	Card High	Temp High	1
Subject 9	Card Med	Temp Med	1	Subject 9	Temp High	Oxy High	0
Subject 10	Vent Med	Card Med	1	Subject 10	Temp High	Oxy High	0
Subject 11	Card Med	Card Med	2	Subject 11	Vent High	Card High	1
Subject 12	Vent Med	Vent Med	0	Subject 12	Vent High	Vent High	0
Subject 13	Temp Med	Card Med	1	Subject 13	Oxy High	Temp High	0
		Total	14			Total	12

OXYGEN MEDIUM was played				OXYGEN HIGH was played			
Subject	Response 1	Response 2	Total Correct Response	Subject	Response 1	Response 2	Total Correct Response
Subject 1	Oxy Med	Oxy Med	2	Subject 1	Card High	Oxy High	1
Subject 2	Oxy Med	Oxy Med	2	Subject 2	Oxy High	Temp High	1
Subject 3	Oxy Med	Oxy Med	2	Subject 3	Card High	Vent High	0
Subject 4	Card Med	Oxy Med	1	Subject 4	Temp High	Card Med	0
Subject 5	Oxy Med	Card Med	1	Subject 5	Vent High	Card High	0
Subject 6	Oxy Med	Temp Med	1	Subject 6	Card High	Card High	0
Subject 7	Oxy Med	Temp Med	1	Subject 7	Vent High	Oxy High	1
Subject 8	Oxy Med	Card Med	1	Subject 8	Oxy High	Vent High	1
Subject 9	Oxy Med	Oxy Med	2	Subject 9	Vent High	Oxy High	1
Subject 10	Oxy Med	Card Med	1	Subject 10	Temp High	Vent High	0
Subject 11	Card Med	Oxy Med	1	Subject 11	Oxy High	Oxy High	2
Subject 12	Oxy Med	Oxy Med	2	Subject 12	Card High	Card High	0
Subject 13	Temp Med	Temp Med	0	Subject 13	Temp High	Temp High	0
		Total	17			Total	7

TEMPURE MEDIUM was played				TEMPERATURE HIGH was played			
Subject	Response 1	Response 2	Total Correct Response	Subject	Response 1	Response 2	Total Correct Response
Subject 1	Temp Med	Temp Med	2	Subject 1	Temp High	Temp High	2
Subject 2	Temp Med	Temp Med	2	Subject 2	Vent High	Vent High	0
Subject 3	Temp Med	Temp Med	2	Subject 3	Temp High	Vent High	1
Subject 4	Vent Med	Vent Med	0	Subject 4	Vent High	Vent High	0
Subject 5	Vent Med	Oxy Med	0	Subject 5	Temp High	Vent High	1
Subject 6	Temp Med	Temp Med	2	Subject 6	Temp High	Vent High	1
Subject 7	Vent Med	Vent Med	0	Subject 7	Vent High	Oxy High	0
Subject 8	Temp Med	Temp Med	2	Subject 8	Temp High	Card High	1
Subject 9	Temp Med	Temp Med	2	Subject 9	Temp High	Card High	1
Subject 10	Temp Med	Temp Med	2	Subject 10	Temp High	Temp High	2
Subject 11	Oxy Med	Temp Med	1	Subject 11	Vent High	Oxy High	0
Subject 12	Temp Med	Temp Med	2	Subject 12	Card High	Temp High	1
Subject 13	Vent Med	Vent Med	0	Subject 13	Vent High	Oxy High	0
		Total	17			Total	10

VENTILATION MEDIUM was played				VENTILATION HIGH was played			
Subject	Response 1	Response 2	Total Correct Response	Subject	Response 1	Response 2	Total Correct Response
Subject 1	Vent Med	Vent Med	2	Subject 1	Card High	Vent High	1
Subject 2	Vent Med	Vent Med	2	Subject 2	Temp High	Vent High	1
Subject 3	Temp Med	Vent Med	1	Subject 3	Vent High	Card Med	1
Subject 4	Oxy Med	Vent Med	1	Subject 4	Temp High	Vent High	1
Subject 5	Oxy Med	Oxy Med	0	Subject 5	Vent High	Vent High	2
Subject 6	Vent Med	Vent Med	2	Subject 6	Card High	Card High	0
Subject 7	Temp Med	Temp Med	0	Subject 7	Oxy High	Temp High	0
Subject 8	Vent Med	Vent Med	2	Subject 8	Oxy High	Oxy High	2
Subject 9	Vent Med	Vent Med	2	Subject 9	Vent High	Vent High	2
Subject 10	Vent Med	Oxy Med	1	Subject 10	Temp High	Temp High	0
Subject 11	Oxy Med	Oxy Med	0	Subject 11	Temp High	Temp High	0
Subject 12	Vent Med	Card Med	1	Subject 12	Oxy High	Card High	0
Subject 13	Oxy Med	Oxy Med	0	Subject 13	Card High	Oxy High	0
		Total	14			Total	10

Annoyance Urgency Data

CARDIAC MEDIUM was played

	Annoyance				Urgency			
Subject	Response 1	Response 2	Response 3	Mean	Response 1	Response 2	Response 3	Mean
Subject 1	5	5	5	5.00	2	3	2	2.33
Subject 2	4	4	4	4.00	4	3	4	3.67
Subject 3	3	6	3	4.00	3	6	3	4.00
Subject 4	4	1	1	2.00	5	1	2	2.67
Subject 5	2	2	2	2.00	4	3	2	3.00
Subject 6	1	2	2	1.67	3	1	2	2.00
Subject 7	1	1	5	2.33	4	4	5	4.33
Subject 8	3	4	4	3.67	3	3	3	3.00
Subject 9	3	3	4	3.33	4	5	3	4.00
Subject 10	5	6	2	4.33	2	2	6	3.33
Subject 11	2	2	2	2.00	2	2	2	2.00
Subject 12	3	3	3	3.00	4	5	5	4.67
Subject 13	1	1	1	1.00	1	1	1	1.00
			Mean	2.95			Mean	3.08

CARDIAC HIGH was played

	Annoyance				Urgency			
Subject	Response 1	Response 2	Response 3	Mean	Response 1	Response 2	Response 3	Mean
Subject 1	5	7	7	6.33	5	5	4	4.67
Subject 2	6	5	6	5.67	5	5	6	5.33
Subject 3	7	6	7	6.67	7	6	7	6.67
Subject 4	3	4	1	2.67	4	1	3	2.67
Subject 5	2	2	2	2.00	3	5	5	4.33
Subject 6	1	2	2	1.67	3	3	5	3.67
Subject 7	1	1	1	1.00	5	6	6	5.67
Subject 8	1	2	4	2.33	2	3	5	3.33
Subject 9	2	4	4	3.33	5	6	6	5.67
Subject 10	2	2	2	2.00	6	6	6	6.00
Subject 11	2	3	3	2.67	2	2	3	2.33
Subject 12	2	2	4	2.67	6	7	7	6.67
Subject 13	1	1	1	1.00	3	3	4	3.33
			Mean	3.08			Mean	4.64

OXYGEN MEDIUM was played

	Annoyance				Urgency			
Subject	**Response 1**	**Response 2**	**Response 3**	**Mean**	**Response 1**	**Response 2**	**Response 3**	**Mean**
Subject 1	4	5	5	**4.67**	3	4	3	**3.33**
Subject 2	4	4	5	**4.33**	4	4	5	**4.33**
Subject 3	7	7	3	**5.67**	7	7	3	**5.67**
Subject 4	2	5	1	**2.67**	4	4	1	**3.00**
Subject 5	2	1	2	**1.67**	2	2	2	**2.00**
Subject 6	1	1	2	**1.33**	2	2	1	**1.67**
Subject 7	1	1	1	**1.00**	4	4	6	**4.67**
Subject 8	1	1	2	**1.33**	2	2	2	**2.00**
Subject 9	3	3	3	**3.00**	3	3	3	**3.00**
Subject 10	3	4	5	**4.00**	4	2	2	**2.67**
Subject 11	2	2	3	**2.33**	2	2	3	**2.33**
Subject 12	2	2	6	**3.33**	4	4	5	**4.33**
Subject 13	1	1	1	**1.00**	1	1	2	**1.33**
			Mean	**2.79**			**Mean**	**3.10**

OXYGEN HIGH was played

	Annoyance				Urgency			
Subject	**Response 1**	**Response 2**	**Response 3**	**Mean**	**Response 1**	**Response 2**	**Response 3**	**Mean**
Subject 1	5	4	6	**5.00**	4	4	4	**4.00**
Subject 2	5	4	5	**4.67**	5	4	5	**4.67**
Subject 3	5	5	5	**5.00**	6	5	5	**5.33**
Subject 4	3	6	2	**3.67**	1	6	3	**3.33**
Subject 5	1	2	2	**1.67**	4	4	5	**4.33**
Subject 6	1	2	2	**1.67**	4	1	3	**2.67**
Subject 7	1	1	1	**1.00**	3	5	6	**4.67**
Subject 8	2	3	3	**2.67**	4	4	5	**4.33**
Subject 9	3	3	3	**3.00**	5	6	6	**5.67**
Subject 10	2	2	2	**2.00**	6	6	6	**6.00**
Subject 11	3	3	3	**3.00**	2	2	2	**2.00**
Subject 12	2	3	4	**3.00**	6	7	6	**6.33**
Subject 13	1	1	1	**1.00**	3	3	4	**3.33**
			Mean	**2.87**			**Mean**	**4.36**

TEMPERATURE MEDIUM was played

	Annoyance				Urgency			
Subject	**Response 1**	**Response 2**	**Response 3**	**Mean**	**Response 1**	**Response 2**	**Response 3**	**Mean**
Subject 1	5	4	6	**5.00**	4	4	4	**4.00**
Subject 2	5	4	5	**4.67**	5	4	5	**4.67**
Subject 3	5	5	5	**5.00**	6	5	5	**5.33**
Subject 4	3	6	2	**3.67**	1	6	3	**3.33**
Subject 5	1	2	2	**1.67**	4	4	5	**4.33**
Subject 6	1	2	2	**1.67**	4	1	3	**2.67**
Subject 7	1	1	1	**1.00**	3	5	6	**4.67**
Subject 8	2	3	3	**2.67**	4	4	5	**4.33**
Subject 9	3	3	3	**3.00**	5	6	6	**5.67**
Subject 10	2	2	2	**2.00**	6	6	6	**6.00**
Subject 11	3	3	3	**3.00**	2	2	2	**2.00**
Subject 12	2	3	4	**3.00**	6	7	6	**6.33**
Subject 13	1	1	1	**1.00**	3	3	4	**3.33**
			Mean	**2.87**			**Mean**	**4.36**

TEMPERATURE HIGH was played

	Annoyance				Urgency			
Subject	**Response 1**	**Response 2**	**Response 3**	**Mean**	**Response 1**	**Response 2**	**Response 3**	**Mean**
Subject 1	6	6	5	**5.67**	4	3	4	**3.67**
Subject 2	4	4	4	**4.00**	4	4	4	**4.00**
Subject 3	4	4	3	**3.67**	4	4	3	**3.67**
Subject 4	3	1	2	**2.00**	1	2	3	**2.00**
Subject 5	2	1	2	**1.67**	4	5	5	**4.67**
Subject 6	1	1	2	**1.33**	2	3	4	**3.00**
Subject 7	1	1	1	**1.00**	4	4	5	**4.33**
Subject 8	3	3	4	**3.33**	4	4	5	**4.33**
Subject 9	3	4	4	**3.67**	5	6	6	**5.67**
Subject 10	2	2	3	**2.33**	6	6	2	**4.67**
Subject 11	2	2	2	**2.00**	2	2	3	**2.33**
Subject 12	3	3	4	**3.33**	7	7	7	**7.00**
Subject 13	1	1	1	**1.00**	2	3	3	**2.67**
			Mean	**2.69**			**Mean**	**4.00**

VENTILATION MEDIUM was played

	Annoyance				Urgency			
Subject	Response 1	Response 2	Response 3	Mean	Response 1	Response 2	Response 3	Mean
Subject 1	4	4	5	4.33	3	3	3	3.00
Subject 2	3	3	3	3.00	3	4	4	3.67
Subject 3	3	5	5	4.33	3	5	5	4.33
Subject 4	1	3	1	1.67	2	4	2	2.67
Subject 5	2	1	1	1.33	3	2	3	2.67
Subject 6	1	2	3	2.00	2	2	1	1.67
Subject 7	1	1	1	1.00	3	3	4	3.33
Subject 8	2	2	2	2.00	1	3	4	2.67
Subject 9	2	3	4	3.00	3	3	3	3.00
Subject 10	1	2	5	2.67	3	2	2	2.33
Subject 11	2	2	2	2.00	2	2	2	2.00
Subject 12	2	3	4	3.00	4	4	5	4.33
Subject 13	1	1	1	1.00	1	1	1	1.00
			Mean	2.41			Mean	2.82

VENTILATION HIGH was played

	Annoyance				Urgency			
Subject	Response 1	Response 2	Response 3	Mean	Response 1	Response 2	Response 3	Mean
Subject 1	5	6	4	5.00	3	4	4	3.67
Subject 2	3	3	4	3.33	4	4	4	4.00
Subject 3	2	4	4	3.33	2	4	4	3.33
Subject 4	2	5	2	3.00	4	2	4	3.33
Subject 5	2	1	1	1.33	4	5	5	4.67
Subject 6	1	1	2	1.33	2	2	4	2.67
Subject 7	1	1	1	1.00	3	5	6	4.67
Subject 8	3	3	3	3.00	3	4	5	4.00
Subject 9	4	4	4	4.00	6	6	6	6.00
Subject 10	2	5	5	4.00	6	2	3	3.67
Subject 11	2	2	3	2.33	2	3	3	2.67
Subject 12	2	3	3	2.67	7	7	7	7.00
Subject 13	1	1	1	1.00	3	3	4	3.33
			Mean	2.72			Mean	4.08

Identification without Noise

CARDIAC MEDIUM was played					CARDIAC HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Card Med	Card Med	Card Med	3	**Subject 1**	Card High	Card High	Card High	3
Subject 2	Card Med	Card Med	Oxy Med	2	**Subject 2**	Oxy High	Vent High	Card High	1
Subject 3	Vent Med	Card Med	Card Med	2	**Subject 3**	Card High	Card High	Card High	3
Subject 6	Temp Med	Oxy Med	Temp Med	0	**Subject 6**	Oxy High	Oxy High	Vent High	0
Subject 8	Temp Med	Card Med	Card Med	2	**Subject 8**	Temp High	Vent High	Card High	1
Subject 9	Card Med	Card Med	Card Med	3	**Subject 9**	Oxy High	Temp High	Vent High	0
			Total	12				Total	8

OXYGEN MEDIUM was played					OXYGEN HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Oxy Med	Oxy Med	Oxy Med	3	**Subject 1**	Oxy High	Oxy High	Oxy High	3
Subject 2	Oxy Med	Oxy Med	Card Med	2	**Subject 2**	Card High	Temp High	Oxy High	1
Subject 3	Vent Med	Vent Med	Card Med	0	**Subject 3**	Temp High	Card High	Vent Med	0
Subject 6	Card Med	Vent Med	Vent Med	0	**Subject 6**	Vent High	Vent High	Card High	0
Subject 8	Card Med	Card Med	Card Med	0	**Subject 8**	Oxy High	Oxy High	Temp High	2
Subject 9	Vent Med	Vent Med	Vent Med	0	**Subject 9**	Vent High	Oxy High	Oxy High	2
			Total	5				Total	8

TEMPERATURE MEDIUM was played					TEMPERATURE HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Temp Med	Temp Med	Temp Med	3	**Subject 1**	Temp High	Temp High	Temp High	3
Subject 2	Card Med	Temp Med	Card Med	1	**Subject 2**	Vent High	Oxy High	Temp High	1
Subject 3	Temp Med	Temp Med	Temp Med	3	**Subject 3**	Vent High	Vent High	Vent High	0
Subject 6	Temp Med	Temp Med	Oxy Med	2	**Subject 6**	Card High	Vent High	Vent High	0
Subject 8	Vent Med	Vent Med	Vent Med	0	**Subject 8**	Vent High	Temp High	Vent High	1
Subject 9	Oxy Med	Oxy Med	Card Med	0	**Subject 9**	Temp High	Temp High	Temp Med	2
			Total	9				Total	7

VENTILATION MEDIUM was played					VENTILATION HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Vent Med	Vent Med	Vent Med	3	**Subject 1**	Vent High	Vent High	Card High	2
Subject 2	Card Med	Vent Med	Vent Med	2	**Subject 2**	Temp High	Vent High	Oxy High	1
Subject 3	Temp Med	Vent Med	Vent Med	2	**Subject 3**	Card High	Temp High	Vent High	1
Subject 6	Oxy Med	Temp Med	Temp Med	0	**Subject 6**	Temp High	Card High	Oxy High	0
Subject 8	Card Med	Temp Med	Oxy Med	0	**Subject 8**	Vent High	Card High	Vent High	2
Subject 9	Temp Med	Temp Med	Temp Med	0	**Subject 9**	Temp High	Vent High	Oxy High	1
			Total	7				Total	7

Identification with Noise

CARDIAC MEDIUM was played					CARDIAC HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Card Med	Temp Med	Card Med	2	**Subject 1**	Card High	Card High	Card High	3
Subject 2	Card Med	Card Med	Card Med	3	**Subject 2**	Vent High	Vent High	Card High	1
Subject 3	Card Med	Temp Med	Card Med	2	**Subject 3**	Card High	Vent High	Vent High	1
Subject 6	Oxy Med	Oxy Med	Card Med	1	**Subject 6**	Temp High	Card High	Card High	2
Subject 8	Card Med	Card Med	Vent Med	2	**Subject 8**	Temp High	Vent High	Temp High	0
Subject 9	Card Med	Temp Med	Oxy Med	1	**Subject 9**	Vent High	Temp High	Temp High	0
			Total	11				Total	7

OXYGEN MEDIUM was played					OXYGEN HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Oxy Med	Oxy Med	Oxy Med	3	**Subject 1**	Oxy High	Oxy High	Oxy High	3
Subject 2	Card Med	Card Med	Vent Med	0	**Subject 2**	Oxy High	Card High	Vent High	1
Subject 3	Vent Med	Temp Med	Oxy Med	1	**Subject 3**	Vent High	Vent Med	Card High	0
Subject 6	Vent Med	Temp Med	Vent Med	0	**Subject 6**	Vent High	Vent High	Oxy High	1
Subject 8	Card Med	Vent Med	Oxy Med	1	**Subject 8**	Vent High	Oxy High	Card High	1
Subject 9	Vent Med	Vent Med	Oxy Med	1	**Subject 9**	Oxy High	Vent High	Oxy High	2
			Total	6				Total	8

TEMPERATURE MEDIUM was played					TEMPERATURE HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Temp Med	Temp Med	Temp Med	3	**Subject 1**	Temp High	Temp High	Temp High	3
Subject 2	Vent Med	Temp Med	Temp Med	2	**Subject 2**	Temp High	Temp High	Oxy High	2
Subject 3	Vent Med	Vent Med	Vent Med	0	**Subject 3**	Temp Med	Temp High	Vent High	1
Subject 6	Oxy Med	Vent Med	Temp Med	1	**Subject 6**	Oxy High	Card High	Vent High	0
Subject 8	Card Med	Card Med	Vent Med	0	**Subject 8**	Temp High	Vent High	Oxy High	1
Subject 9	Vent Med	Temp Med	Card Med	1	**Subject 9**	Card High	Card High	Oxy High	0
			Total	7				Total	7

VENTILATION MEDIUM was played					VENTILATION HIGH was played				
Subject	Response 1	Response 2	Response 3	Total Correct Response	**Subject**	Response 1	Response 2	Response 3	Total Correct Response
Subject 1	Card Med	Card Med	Vent Med	1	**Subject 1**	Card High	Temp High	Vent High	1
Subject 2	Vent Med	Temp Med	Oxy Med	1	**Subject 2**	Vent High	Oxy High	Vent High	2
Subject 3	Temp Med	Vent Med	Vent Med	2	**Subject 3**	Temp High	Vent Med	Card High	0
Subject 6	Temp Med	Temp Med	Temp Med	0	**Subject 6**	Card High	Oxy High	Oxy High	0
Subject 8	Vent Med	Vent Med	Oxy Med	2	**Subject 8**	Oxy High	Card High	Card High	0
Subject 9	Temp Med	Card Med	Card Med	0	**Subject 9**	Temp High	Vent High	Vent High	2
			Total	6				Total	5

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