
A PROPOSED NEW SET OF ALARM SOUNDS WHICH SATISFY STANDARDS AND RATIONALE TO ENCODE SOURCE INFORMATION

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INTRODUCTION AND BACKGROUND

Existing national and international 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 (Figure 1a). The high priority sound could be described as three quarter-notes, a quarter-rest, and two quarter-notes (Figure 1b). 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 [1, 2], though the United States standard requires the use of musical pitches (piano scale) [3].

In an earlier effort at standardizing alarm sounds, Dr Roy Patterson proposed sounds related to six 'organ systems.' 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 six systems are shown in Table 1. Energy delivery is included with temperature; this concept refers to (for instance) delivery of energy from a diagnostic or therapeutic radiation device. Drug delivery includes infusion pumps and anesthetic vaporizers. Artificial circulation comprises cardiopulmonary bypass machines, intra-aortic balloon pumps, and similar equipment [4]. There was also a 'general' sound, which could be used by any device. Patterson's sounds did not conform to a specific rhythmic pattern; instead, each sound had its own rhythm, to confer additional distinctiveness. Many observers did not understand the sense behind the Patterson sounds, and therefore found them laughable or deplorable [5]. (It should be noted that

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Fig. 1. Rhythm of the medium- and high-priority alarm sounds (fixed pitch).

Table 1. The six organ systems used by Dr Roy Patterson

Oxygenation
Ventilation
Cardiovascular
Temperature or energy delivery
Drug delivery
Artificial circulation

Patterson's sounds were designed for demonstration purposes only; they were never intended to be the final sounds used on medical devices.)

Block proposed (somewhat facetiously) an alternate set of 'organ system' sounds, in which each system was mapped onto a popular tune. For instance, the cardiovascular sound was to the tune of, 'I left my heart in San Francisco' [6]. 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 for these 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. The problem of false alarms, and this confusion of alarm sources, are two of the major complaints about present alarms [7].

In the mid-1990s, Block and Rouse composed proprietary sounds for Datex-Ohmeda (Figure 2a and b). 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 which can be configured by the hospital through the use of a password. While there are no formal data on operator acceptance of these sounds, the authors esti-

mate that approximately 80% of operators appreciate these sounds, but the other 20% of operators do not care for them.

Presently the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) have convened a Joint Working Group (JWG) on Alarm signals. This group is drafting a collateral standard to IEC 60601: Medical electrical equipment - Part 1: General requirements for safety. This collateral standard will be 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 current draft follows the previous conventions for the rhythms and pitches of the alarm sounds.

Patterson found that naïve subjects could quickly learn 6 different alarm sounds, and that, with additional effort, they could learn up to 10 different sounds [8]. (Furthermore, as the present authors have noted above, many listeners may be able to distinguish an even larger number of melodies.) In addition, an informal survey of anesthesiologists in 1993 suggested that most would prefer to have alarm sounds encoded by organ system [9]. Another informal survey in 2000 showed a near 50-50 split, with half who preferred a single alarm sound, and half who preferred the encoded sounds.

The JWG preferred to have the sounds encoded by device, rather than by organ system. In that way, the operator could more easily identify which of several devices was alarming. Still the organ system sounds could be easily applied to a device, as indicated below.

METHOD

More recently, to satisfy these wishes, Block, Hakala, and Thompson have composed a set of device-specific sounds. Six sounds for the historical 'organ system' are provided, plus a 'general' sound, plus an additional sound for a new category, Power Failure. These eight sounds, plus a ninth sound for a low-priority alarm, are shown in Figure 3 and described in Table 2.

The goal of these small melodies is to provide alarm sounds which comply with all the requirements of the



Fig. 2. The Block-Rouse sounds; used in the Datex-Ohmeda AS/3 monitor.

<p>3. General, Medium Priority</p>	<p>General, High Priority</p>
<p>Oxygen, Medium Priority</p> <p>Ox - y - gen</p>	<p>Oxygen, High Priority</p> <p>Ox - y - gen A - larm</p>
<p>Ventilation, Medium Priority</p> <p>Ven - ti - late</p>	<p>Ventilation, High Priority</p> <p>Ven - ti - la - ti - on</p>
<p>Cardiovascular, Medium Priority</p> <p>Car - di - ac</p>	<p>Cardiovascular, High Priority</p> <p>Car - di - ac A - larm</p>
<p>Temperature, Medium Priority</p> <p>Tem - p'ra - ture</p>	<p>Temperature, High Priority</p> <p>Tem - p'ra - ture A - larm</p>
<p>Drug Delivery, Medium Priority</p> <p>In - fu - sion</p>	<p>Drug Delivery, High Priority</p> <p>In - fu - sion A - larm</p>
<p>Artificial Perfusion, Medium Priority</p> <p>Per - fu - sion</p>	<p>Artificial Perfusion, High Priority</p> <p>Per - fu - sion A - larm</p>
<p>Power Failure, Medium Priority</p> <p>Pow - er Fail</p>	<p>Power Failure, High Priority</p> <p>Pow - er Go - ing Down</p>
<p>Low Priority</p> <p>In - fo</p>	

Fig. 3. The proposed new sounds by 'organ system'.

Table 2. Proposed standard-compatible, device-specific alarm sounds

Auditory alarm category	Medium priority alarm (Mnemonic)	High priority alarm (Mnemonic and other information)	Typical equipment
General	C4 C4 C4 Note 2	C4 C4 C4 - C4 C4 (Fixed pitch; traditional (usual) 9703 sound)	Other equipment which does not readily fall into one of the following categories, including but not limited to electrical or non-oxygen gas supply systems, EEG monitors, intracranial pressure monitors, laparoscopic gas insufflation systems, calf compressor systems, etc. Optionally this sound may be used by any medical equipment
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)	Pulse oximeters, transcutaneous/tissue oxygen monitors, oxygen analyzers, oxygen concentrators, oxygen gas supply lines
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 Old 'NBC Chime'; inverted major chord; rise and fall of the lungs)	Workstations which included artificial ventilators (but which do not include cardiac monitors); artificial ventilators, spirometers, CO2 monitors, ventilator disconnect (airway pressure) monitors, etc.
Cardiovascular	C4 E4 G4 (CAR-DI-AC)	C4 E4 G4 - G4 C5 (CAR-DI-AC A-LARM Trumpet call; call to arms; major chord)	Workstations which include cardiac monitors, multi-parameter monitors which include cardiac monitors, heart rate monitors, invasive or non-invasive blood pressure monitors, cardiac output monitors, peripheral perfusion monitors (plethysmographs), transesophageal echo, fetal heart rate monitors
Temperature or delivery of energy	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)	Temperature monitors, heated air humidifiers, infant radiant warmers, neonatal incubators, patient heating or cooling systems, blood or fluid warmers; electrocautery, ultrasound, laser, X-ray or MRI systems, nerve stimulators
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)	Volumetric infusion pumps, syringe drivers, anesthetic agent delivery systems or analyzers
Artificial perfusion	C4 F#4 C4 (PER-FU-SION)	C4 F#4 C4 - C4 F#4 (PER-FU-SION A-LARM Artificial sound; Tri-tone; similar to 'Yo-ee-oh' of the Munchkins in 'The Wizard of Oz')	Cardio-pulmonary perfusion pumps ('heart-lung machines') and associated equipment, intra-aortic balloon pumps, ventricular assist devices; artificial hearts; renal dialysis systems
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)	Any device when it experiences loss of power or other major failure of the device
Low priority alarm	E4 C4 (low priority) (IN-FO; MESS-AGE; ding-dong; doorbell or hostess call)	-	

There are several competing systems of musical notation. The authors follow the system of International Pitch Notation (IPN), which was created under the auspices of the Acoustical Society of America. C4, D4, E4, F4, G4, A4, B4 refer to Middle C on a piano and the octave above Middle C. C5 is the C above Middle C on a piano. A4 = 440 Hz [11].

existing ISO, CEN, and ASTM standards, and which will presumably comply with the new collateral standard that is under development. Possibly additional sounds could be composed, to allow for additional distinctiveness for other kinds of medical devices and situations, but the authors wished to minimize the number of sounds to be learned.

The rhythmic limitations of the sounds, as defined in the standards, are severe. Concern has also been raised in the JWG discussions and elsewhere that these rhythms may not convey the proper sense of urgency. Nonetheless, the authors believe that the sounds, and their associated level of urgency, can be learned.

A further requirement for a scheme of 8 sounds is that they must be identifiable in the first three notes – that is, in the three notes of the medium-priority sound. The pitch can rise, fall, or stay the same between each sequential pair of the three notes. Thus the nine possible patterns are shown in Table 3.

The initial decision was to try to avoid using two sequential pitches that were the same, except in the ‘general’ sound. (The general sound follows the constant pitch pattern that many manufacturers have already chosen.) It is recognized that many operators may be ‘tone deaf’ and may have difficulty in distinguishing pitch changes [10]. Therefore any two alarm sounds with the same general melodic pattern must have substantially different pitch intervals. For example, both the Cardiovascular and Temperature sounds use a rise–rise pattern, but the pitch intervals are larger in the Cardiovascular sound.

Every sound was assigned a mnemonic – a small phrase that could be ‘sung’ to the sound. Every sound also was specifically composed so that the changing pitches might suggest the nature of the device, for instance, the rise-and-fall of the lungs during mechanical ventilation. It was recognized that the drug delivery sound would be included in infusion pumps, and that infusion pumps would perhaps be the most common devices used in lower-level care areas such as ordinary patient wards. For that reason, the drug delivery sound was deliberately made more dissonant than the others (9th chord). In this way, family members or others might be inspired to obtain assistance in addressing the alarm.

DISCUSSION

One valid question is the proper role of auditory and visual alarm signals. Some experts believe that the auditory signal should merely gain the operator’s attention, and that visual signals should direct the operator

Table 3. The possible pitch patterns of a three-note phrase

Rise–rise
Rise–same
Rise–fall
Same–rise
Same–same
Same–fall
Fall–rise
Fall–same
Fall–fall

to the appropriate device and alarm condition. A centralized alarm screen might serve this function in a bedside workstation; alarm lights in a corridor might serve the same function to direct a caregiver to the appropriate room. On the other hand, other experts believe that it is wise to make use of the ability to encode additional information within the alarm sounds themselves [9].

These sounds are merely a proposal; they have not undergone any formal testing. It is expected that most operators would learn these sounds, so that they would rapidly be able to identify the alarming device. Formal testing should be done to confirm or refute this prediction. Unfortunately, there has been no published formal testing of any of the existing standard alarm rhythms or of any schemes for melodies. Nonetheless, the existing standard rhythms and these melodies are expected to be included as one possible scheme of sounds that meet the requirements of the JWG alarms document. Encoding the sounds might also help prevent confusion which would otherwise result if different manufacturers chose different melodies for their equipment.

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