"For if the trumpet give an uncertain sound, who shall prepare himself to the battle?" (I Corinthians 14:8, KJV)

Frank E. Block, Jr., MD

Every clinician is well aware of the problems with audible alarms: False alarms, loud alarms, difficulty determining what is alarming, and inability to quiet an alarm all create distractions that impede patient care. These problems are complicated by the different approaches to alarms among devices. Devices designed by various manufacturers may use different alarm sounds to identify similar events or, alternately, similar sounds may be produced to identify unrelated events.[1–3] Over several years, the International Organization for Standardization/International Electrotechnical Commission (ISO/IEC) Joint Working Group on Alarms (JWG) developed a standard for audible alarms that suggests the use of melodic tones to identify untoward physiologic changes (IEC 60601-1-8).[4] In this issue of the journal, Wee and Sanderson[5] report a study documenting the challenges in training nursing personnel to use audible alarms that conform to the IEC standard. These authors conclude that "The slow rate of learning and persistent confusions suggest that the IEC 60601-1-8 melodic alarms should be redesigned before they are adopted for clinical practice." These findings bring the utility of the existing standard into question and, more importantly, challenge us to consider what alarm sounds might actually address the problems with audible alarms.

In the 1980s, national standards writing groups began to standardize alarm signals. The British standards group approached Dr. Roy Patterson, a prominent acoustician experienced with alarm design, for assistance. The group told Dr. Patterson that there were "six ways to kill people" (oxygen, ventilation, cardiovascular, temperature/energy delivery, drug infusion, and artificial perfusion). Patterson designed a set of seven prototype alarm sounds, one for each of the six "organ systems" plus a general sound. Each sound had a high-priority form and a medium-priority form that were very similar, but the high-priority version was faster and sounded more urgent. The general alarm also included an optional low-priority alarm sound.[6]

When Patterson's proposed eight alarm sounds were played for various clinicians, the usual reaction was one of astonishment or amusement. To the unknowing ear, they sounded like a set of random electronic noises. Many supposed authorities, including this author, set out to debunk the Patterson sounds, lest they should be adopted by the standards groups and forced upon clinicians worldwide.

This author, in opposing the Patterson sounds, suggested that musical alarm sounds might be easier to learn. For instance, the cardiac alarm might be to the tune of "I Left My Heart in San Francisco." At a dinner at the American Society of Anesthesiologists Annual Meeting in 1990, a learning exercise with possible musical alarm sounds suggested that they could be learned quickly.[7] The United States standards committee accepted the suggestion of melodic alarms and required that medical alarms should use standard musical pitches.[8] The International Standards Committee that wrote the ISO 9703-2 alarm standard in the 1990s abandoned the Patterson sounds and decided upon a 3-note medium priority alarm sound and a 5-note high-priority sound.[9] The musical pitches were not specified,

From the Department of Anesthesiology, University of Arkansas for Medical Sciences, Little Rock, Arkansas.

Accepted for publication October 16, 2007.

Conflict of Interest: Dr. Block receives compensation as a consultant to Draeger Medical Systems, Andover, Massachusetts.

Address correspondence and reprint requests to Frank E. Block, Jr., MD, 4301 West Markham Street #515, Little Rock, AR 72205. Address e-mail to BlockFrankE@uams.edu.

DOI: 10.1213/ane.0b013e3181606927

however, and most manufacturers used a single pitch rather than a melody. Therefore, most of the equipment was making the same sound, precisely the situation that the committee hoped to avoid!

Around that time, this author spent several days in discussions with Dr. Patterson. The well-thought-out design behind the sounds had not been conveyed to the critics. First, Dr. Patterson never intended that all the sounds would coexist in a single environment; instead he envisioned a central alarm display in an integrated workstation. One would hear the general sound and look at the central display to identify the problem. The organ system sounds would be used only in special situations (such as the cardiovascular sound in a cardiac care unit, or in the case of nonintegrated equipment). Second, the sounds were designed to be easily discriminated. They differed from each other in their timbre, tempo, rhythm, and number of pulses. Finally, each of the organ system sounds had a mnemonic; in fact each sound had a mnemonic for English, French, and German. The oxygen alarm sounded like the word "ox-y-gen," and the cardiovascular alarm sounded like the word "car-di-o-vas-cu-lar." The existence of these mnemonics was unknown among the standards groups and the critics.

Patterson described his own preference for teaching alarm sounds, which is "one plus one" teaching. In this method, one sound is selected at random and presented to the subject with its meaning. Then the (one) sound is played again and the subject is asked to identify it. (Probably with only one sound the subject gets it correct!) Then a second sound, randomly selected, is introduced along with its meaning. The subject then hears the two sounds in random order, with correction if he/she misses one, until he/she gets both of them correct. Then a third sound is introduced and the three sounds are presented in random order until the subject can identify all three correctly, and so on. As Patterson says, with this method people can learn a set of well-designed alarm sounds about as quickly as one can play them.

In the late 1990s, the JWG decided to retain the 3- and 5-note patterns for the 60601-1-8 alarms standard.[4] Several members of the JWG created a set of melodic alarm sounds that complied with the standard.[10] A new category for "power failure" was added, for a total of 7 "organ systems." Whereas the Patterson sounds for high and medium priority were basically the same (as noted above), the 3-note and 5-note patterns in this new set were not related in any consistent way, and thus there were effectively two different sounds for each organ system. Therefore, in the new set there were 17 different sounds compared to Patterson's 8: a high priority sound and a medium priority sound for each of the 7 "organ systems" plus 3 sounds for the 3 priority levels of the general alarm. The design challenges were overwhelming because the rhythm and the number of notes were fixed. Furthermore, the eight medium priority sounds had to be distinctive in just three notes! The designers realized that the task was really impossible, but they also believed that the sounds they designed were about as good as could ever be made within the limitations of the standard.

All the studies of the 60601-1-8 melodic sounds have pointed out their inadequacies.[5,11–13] This finding comes as no surprise. One major problem is that there are too many alarm sounds. Some authors have suggested that people can learn a maximum of 4–6 sounds, and others a maximum of 5–9 or 6–10, but few have suggested more.[14,15] There are also significant problems with the sounds themselves.

The question, of course, is what one might do next. One of the JWG members has proposed changing the high priority alarm from the present 3 + 2 pattern to a 3 + 3 pattern. Thus the high priority signal would consist of the same tones as the medium priority signal, but played twice and at a faster speed. This approach would reduce the number of different sounds from 17 to 9, but many of the 3-note patterns would remain hard to discriminate.

A second option would be to decrease the number of organ systems, and thus the number of sounds to learn and remember. Perhaps the alarm categories could be reduced to three:

1. Oxygenation (including ventilation)
2. Cardiovascular (including artificial perfusion and cardiac drug infusions)
3. General (including temperature/energy delivery, power failure, and noncardiac drug infusions)

The major problem, however, is that the published standards, and the very idea of melodic alarm sounds, ignore practically all the research that has been done on the design of alarm sounds.[15–18] A modern, evidence-based set of alarm sounds would not be a set of melodies. The two suggestions above, with their continued use of melodic alarm sounds, would still not result in a set of appropriate sounds. It would be a shame to continue with second-rate (or worse) alarm sounds when modern science would allow the creation of a proper set of sounds.

This author would like to take this opportunity to apologize to the medical community for his role in derailing the Patterson alarm sounds nearly two decades ago. I now believe that the Patterson sounds were genius, and that they should have been adopted 10 or 20 years ago.

My final recommendation, therefore, is that the Patterson sounds should be slightly modified and improved, based upon today's knowledge of how to design alarm sounds. (The number of organ systems remains open for further discussion, but a properly designed set of sounds could include 8–9 sounds, depending upon whether the power failure category is retained.) The modified Patterson sounds should then be formally tested. If they can be learned and discriminated successfully, they could be used by any manufacturer without waiting for the JWG to change the

standard. The standard specifically permits alternative alarm sounds if they "provide at least an equivalent degree of safety as the standard sounds."[4] In the case of the proposed modified Patterson sounds, it seems likely that studies would show a higher degree of safety.

In conclusion, we have suffered long enough with poorly-designed alarm sounds. It is time to correct the mistakes of the past, and move forward.

> A man should never be ashamed to own he has been in the wrong, which is but saying, in other words, that he is wiser today than he was yesterday.
>
> –Alexander Pope (1688–1744)[19]

ACKNOWLEDGMENTS

The author would like to thank Judy Edworthy, Robert G. Loeb, and Steven Dain for their helpful comments on this editorial.

REFERENCES

1. Block FE Jr. Human factors and alarms. In: Lake CL, ed. Clinical monitoring for anesthesia & intensive care. Philadelphia: WB Saunders, 1994
2. Block FE Jr, Schaaf C. Auditory alarms during anesthesia monitoring with an integrated monitoring system. Int J Clin Monit Comput 1996;13:81–4
3. Block FE Jr, Nuutinen L, Ballast B. Optimization of alarms: a study on alarm limits, alarm sounds, and false alarms, intended to reduce annoyance. J Clin Monit Comput 1999;15:75–83
4. IEC 60601-1-8 (2005–08): Medical electrical equipment – Part 1–8: General requirements for safety – Collateral standard: general requirements, tests and guidance for alarm systems in medical electrical equipment and medical electrical systems. Geneva, Switzerland: International Electrotechnical Commission, 2005
5. Wee AN, Sanderson PM. Are medical equipment alarms easily learned? Anesth Analg 2008;106:501–8
6. Patterson RD, Edworthy J, Shailer MJ, Lower MC, Wheeler PD. Alarm sounds for medical equipment in intensive care areas and operating theatres. Southampton: Institute of Sound and Vibration Research Report No. AC598, 1986
7. Block FE Jr. Evaluation of users' abilities to recognize musical alarm tones. J Clin Monit 1992;8:285–90
8. ASTM F1463-93. Standard specification for alarm signals in medical equipment used in anesthesia and respiratory care. West Conshohocken, Pennsylvania: ASTM, 1993
9. ISO 9703-2:1994. Anaesthesia and respiratory care alarm signals – Part 2: Auditory alarm signals. Geneva, Switzerland: International Organization for Standardization, 1994
10. Block FE Jr, Rouse JD, Hakala M, Thompson CL. A proposed new set of alarm sounds which satisfy standards and rationale to encode source information. J Clin Monit Comput 2000;16:541–6
11. Williams S, Beatty PCW. Measuring the performance of audible alarms for anaesthesia. Physiol Meas 2005;26:571–81
12. Sanderson PM, Wee A, Lacherez P. Learnability and discriminability of melodic medical equipment alarms. Anaesthesia 2006;61:142–7
13. Lacherez P, Seah EL, Sanderson P. Overlapping melodic alarms are almost indiscriminable. Hum Factors 2007;49:637–45
14. Meredith C, Edworthy J. Are there too many alarms in the intensive care unit? An overview of the problem. J Advanced Nursing 1995;21:15–20
15. Edworthy J, Hellier E. Alarms and human behaviour: implications for medical alarms. Brit J Anaesth 2006;97:12–7
16. Edworthy J, Meredith CS. Cognitive psychology and the design of alarm sounds. Med Engl Phys 1994;16:445–9
17. Edworthy J, Adams A. Warning design: a research perspective. London: Taylor & Francis, 1996
18. Edworthy J, Hellier E. Complex nonverbal auditory signals and speech warnings. In: Wogalter MS, ed. Handbook of warnings. Mahwah, New Jersey: Lawrence Erlbaum Associates, 2006
19. Pope A. Thoughts on various subjects; published in Swift's Miscellanies, 1727