

Fewer but better auditory alarms will improve patient safety

J Edworthy, E Hellier

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Auditory warnings and alarms are used throughout the medical environment but often fall short of ideal. In some instances they can be a hindrance rather than a help to medical practice. The main reasons why alarms are less than ideal are: (1) they are used too often and people's hearing as the primary warning sense is overused; (2) false alarm rates are often exceedingly high because trigger points are inappropriately set; and (3) their design is often poor. However, enough is now known about auditory warning design and implementation to overcome many of the traditional problems associated with them. A new draft international standard incorporates many of these measures, and increasing pressure from safety organisations such as the Joint Commission on the Accreditation of Healthcare Organisations in the USA and the National Patient Safety in the UK can help to improve the way that auditory warnings are used in medical care by implementing what is known from research into practice.

Organisations (JACHO), which is an independent US organisation, evaluates quality and safety care in more than 15 000 healthcare organisations in the US and issues patient safety goals annually. In 2003 it made clinical alarm safety one of its patient safety goals in recognition of the fact that patients continue to be injured or killed because of ineffective alarm coverage.

This paper outlines the problems and possible solutions to the problems associated with auditory alarms. Firstly, the primacy of the auditory sense as our warning sense is outlined. This is followed by a brief review of the way auditory alarms are often used badly in practice. "Alarm handling" is then outlined, followed by a discussion of false alarms and how they might be reduced. Issues relating to the design of alarm sounds are reviewed, showing how sounds are often badly designed and are not appropriate for their purpose, and also how research in this area could be applied in order to improve them. A final section draws these points together and suggests ways in which steps can be taken to improve the situation through standards bodies and organisations concerned with encouraging improved safety.

The current focus on patient safety has encouraged experts in subjects such as ergonomics, psychology, and engineering to become involved in research in this area. Scientists other than those with a medical background but with expertise in areas such as information design, risk perception and decision making all have important contributions to make in informing policy and practice in many areas in which patient safety could be improved.

For example, there has been considerable focus on the ways in which information should be presented in order to improve its understanding. Several projects have looked at the ways in which the presentation of medicine labels, packaging, and patient information leaflets can be improved.¹ Projects have also looked at the way medicines are packaged and presented.² Underlying this impetus is the belief that, if we can develop a greater understanding of how we interact with medical equipment and products at a perceptual and cognitive level, then we can improve them so that medical practitioners will be less prone to error. The patient will benefit both from the reduced error rates of the medical practitioner and from his or her own greater facility with the product due to its improved design. However, one sensory modality which is often underused, abused, or simply ignored is that of audition. This also impacts on medical error and patient safety. The Joint Commission on Accreditation of Healthcare

THE AUDITORY SENSE AS A SAFETY DEVICE

Our hearing is our natural warning sense; it does not matter where we are looking or what we are doing, a sound will get our attention if it is loud enough to be heard against the noise background in which the sound occurs. Our natural inclination when hearing a sound is above all to identify its source³ and to search further, usually visually. However, this mechanism works well with real everyday sounds in relatively open environments and is compromised in the medical arena because the environment is very closed and cluttered, the sounds used are usually badly designed acoustically and are relatively meaningless, and there are far too many alarms for them to be effective.

Auditory alarms are, however, intrinsically useful. Warnings research⁴ shows that people comply more readily with auditory than with visual warnings. In addition, anaesthetists' response time to auditory warnings is faster than to visual warnings.⁵

ALARMS IN THE MEDICAL ENVIRONMENT

Alarms are used anywhere where there is equipment of any kind. They are used to monitor patients, to inform of non-critical events, to let the user know that the equipment is working (or malfunctioning), to indicate that the equipment is self-checking during start up, and so on.

See end of article for authors' affiliations

Correspondence to:
Professor J Edworthy,
School of Psychology,
University of Plymouth,
Plymouth, Devon PL4 8AA,
UK; jedworthy@plymouth.
ac.uk

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Alarms can be found in operating theatres, intensive care units, hospital wards, GP surgeries, ambulances, on free standing equipment, and on medical equipment used at home. Fitting alarms is easy; sound chips can be produced at very low cost and fitted to equipment with little trouble. It is therefore quite typical that a relatively complex piece of equipment might produce six or more different alarm sounds. An anaesthetic work station replete with several pieces of apparatus might therefore produce 20 or more different alarm sounds. If one multiplies this by the potential number of pieces of equipment in, say, an intensive care unit, there is clearly a problem.

The most obvious kinds of problems with alarms are that they are irritating and tend to interfere with tasks rather than helping with them. This has been documented on many occasions.⁶ Also, because there are far too many of them, even people regularly working in areas where they hear the alarms on a daily basis cannot recognise more than about half of them.⁷ The more technical kinds of problems that arise with the way alarms are used typically fall into four main areas: (1) "alarm handling"; (2) false alarm rates; (3) the design of the alarm sounds themselves; and (4) the relationship between the alarm sounds and their functions. Each of these four areas is discussed below.

Alarm handling

In all safety critical systems, of which the medical arena is one, alarms proliferate. The study of "alarm handling" is now a legitimate area for research. For much of the time alarms are cancelled and no action may result. This is also true in, for example, the operating theatre where the anaesthetist regularly acknowledges alarms throughout an operation but does not necessarily always take action.

In fact, low priority situations do not typically require auditory signals as there is usually enough time to detect these events visually (either through inspecting displays or the equipment/process/patient directly). The vast majority of alarms heard under this kind of regime are therefore not alarms at all, in the sense that they are not signalling something which requires immediate action or attention. In other safety critical systems such as aviation where alarm protocols have been rigorously examined and developed, the number of alarms has been reduced considerably.⁸

The consequences of providing far too many low priority alarms are manifold. Firstly, they pollute the sound environment and interfere with communication. Secondly, they distract people from what they are doing, thus increasing the probability of medical error. Thirdly, from a human performance viewpoint, low priority alarms have the status of false alarms with the result that people will match their alarm response rate to the perceived false alarm rate of the system.

False alarm rates

False alarm rates are a major problem for medical alarms. Kestin *et al*⁹ showed that alarms heard during 50 separate operations were classified as spurious for 75% of the time and as indicating patient risk only 3% of the time. A more recent study¹⁰ suggests that these false alarm rates may be reducing but, even so, the rate of false alarms is still unacceptably high. A similar study by Block *et al*¹¹ indicated that most anaesthetists switch off alarms, and the main reason given for doing so is the high false alarm rate. The current trend of encouraging anaesthetists not to turn off alarms may help also to encourage them to adjust their alarm settings so that there are fewer false alarms (if they are able to manually adjust them), but this in itself will do nothing to help the problem of irritating, confusing and multiple alarms potentially hindering rather than helping their work.

Research by Bliss and colleagues^{12 13} has shown quite clearly that, if an alarm system is perceived to be 90% reliable,

then people will respond slightly more than 90% of the time. If a system is perceived to be 10% reliable, then they will respond only 10% of the time. Of course, the 10% of the time that they respond to the system is probably not the 10% of the time that the system is signalling correctly, so effectively the alarm system is rendered almost useless when false alarm rates are high. The practical consequence of this is that alarms which are installed on a "better safe than sorry" basis are likely to make responses to them less—rather than more—reliable.

False alarm rates can be improved by using intelligent alarms. For example, studies have shown that intelligent alarm systems can decrease anaesthetists' response time and improve their performance.^{14 15} Even setting alarm limits more diligently can improve alarm systems significantly.¹⁶ There certainly exists a view that, unless alarms are made to be intelligent and are properly set, then it would be better to get rid of them.¹⁷

Design of alarm sounds

Imagine being entrusted with the task of developing the worst alarm signal in the world. Its characteristics might include: being difficult to localise (to hear where the sound is coming from); being readily susceptible to masking by other sounds; being hard to remember, identify and discriminate from other sounds; and it would only be linked to the situation that it is signalling in a very obscure way. From acoustic theory one would apply the knowledge that the brain uses one of two mechanisms to identify the location of a sound, but would remember that neither mechanism functions properly in the mid to moderately high pitched region. One would also apply the knowledge that signals which are acoustically "poor" (possess relatively few harmonics) are less resistant to masking and need to be presented at higher signal-to-noise ratios than signals which are acoustically richer. One would also apply the knowledge that people are not perceptually equipped to retain the absolute pitch values of a tone.¹⁸ Finally, one would note that, although people have a very rich knowledge of sounds and their relationships to sources and objects, this is not true of abstract sounds. Well established research would therefore predict that the idealised worst warning would be a fixed, relatively high-pitched tone with few harmonics. At this point in the design process one may have realised that this worst case alarm is remarkably similar to most of the existing medical alarm sounds already in use.

In essence, the acoustic nature of alarm sounds typically used in medical environments could not be much worse. Many of them are fixed tones, beeps, and bells which provide very little information and serve mainly to annoy. This is not to say that there are not some considerably more effective and ergonomic approaches both in theory and in practice,¹⁹⁻²¹ but these newer systems and sounds have to coexist with less ergonomic systems, so responses are likely to be dictated by the lowest common denominator which is, by and large, unsuitable continuous tone alarms. There is, however, considerable research on the design and development of more ergonomic auditory warnings and alarms²²⁻²⁵ which could be brought to bear in the development of more ergonomic alarm systems.

Relationship between alarm sound and function

The sheer number and design of alarms militates against them being remembered or distinguished from one another. However, other factors which make it hard to remember alarms include the obscurity of the relationship between the warning sound and its meaning, and the probability that similar equipment from different manufacturers will have different alarm sounds on them despite the fact that they perform the same function. Improving the relationship

between alarm sounds and the situations they represent can be achieved both by extending the range of the types of alarm sounds used and by capitalising on the technique of urgency mapping.²⁶ This is a process by which the urgency of the medical signal is indicated in the acoustic nature of the alarm sound. Some examples of equipment possessing rudimentary urgency mapping—for example, different and more or less urgent sounds and colours for “high”, “medium” and “low” priority situations—are now in existence.²⁷ Urgency mapping is also possible for visual signals and warnings both in electronic equipment and on paper, and this area has huge potential across the whole medical warning domain. Alerting systems for GPs’ computerised drug decision making aids is one example.

However, the simplest solution to the problem of understanding the relationship between alarm sound and function is to standardise on alarm sounds. For more than 20 years there has been a move to standardise medical alarms on a patient centred rather than an equipment centred basis.^{28–29} This is based on the premise that equipment constantly changes whereas the functions that they monitor do not. It is therefore much more parsimonious to develop alarms that relate to cardiovascular functions, ventilation considerations, and so on than the equipment which monitors these functions.

ADDRESSING THE PROBLEMS

An ideal alarm system would only warn when appropriate; there would be consistent use of the same alarms for the same functions regardless of organisation or manufacturer; the urgency of alarms would be appropriate to their function; false alarms would be rare rather than common; and the alarms would be easy to learn and retain. Much of this could be achieved through the use of intelligent hierarchical alarm systems where proper consideration of the design of the alarms themselves (and the incorporation of what is known about the design of alarm sounds) is given. Some manufacturers have introduced hierarchical and/or intelligent alarm systems into their products, but the impact of these is necessarily piecemeal. However, these newer systems are more likely to comply with new and future standards and are therefore likely to be more acceptable to purchasers and users. This will help such systems to become more commonplace. Currently these new systems stand alongside the older, less ergonomic systems, but a combination of the passage of time, new technological developments, the development of more comprehensive standards, and the key role of non-government safety organisations such as the JCAHO and the National Patient Safety Agency (NPSA) should help speed the replacement of the old systems with the newer ones.

Key messages

Medical warnings will be more effective if:

- Warning sounds are standardised.
- The acoustic properties of alarms are given proper consideration.
- The learnability of alarms is given proper consideration.
- Prioritisation of alarms is possible within the system.
- The urgency of alarm sounds matches their criticality.
- Trigger points are appropriately set.
- Intelligent alarm systems are used.

A now replaced standard ISO 9703 “Anaesthesia in respiratory care alarm signals”³⁰ considered a system of assigning auditory alarms to physiological functions as outlined by Kerr *et al*²⁹ and a set of alarms was developed to demonstrate the way this would work. However, the final version restricted its remit only to a general alarm with different levels of priority. A newer standard, ISO/IEC 60601 “Medical alarm equipment”³¹ which currently has the status of a draft international standard (DIS) is more general in its remit (as it refers to medical alarms rather than specifically to anaesthesia alarms) and it, too, has developed the idea of having standardised warning sounds. Details of the recommended and alternative alarm systems are presented in this standard. The standard also concerns itself with intelligent alarms, which are known to reduce false alarm rates and therefore to be more reliable, and the use of radiotelemetry which is likely to be more and more significant as technology develops. It also considers issues such as alarm logging and alarm security.

Standardisation is one way of addressing some of the problems currently encountered with the use of alarms as manufacturers will be obliged to meet the requirements of new standards. This in turn will help the NHS and other healthcare providers as they will be in a position to require manufacturers to abide by new standards, which will improve both practice and patient safety. Continued encouragement to improve auditory alarms from bodies such as the JCAHO and the NPSA should also help to improve the current situation.

Authors’ affiliations

J Edworthy, E Hellier, School of Psychology, University of Plymouth, Devon, UK

REFERENCES

- 1 Raynor DK, Knapp P. Do patients see, read and retain the new mandatory medicines information leaflets? *Pharm J* 2002;**264**:268–70.
- 2 Ward J. *Methotrexate: the design lessons*, Paper presented to the 2004 British Association Festival of Science, Exeter University, September, 2004.
- 3 Ballas JA. Common factors in the identification of an assortment of brief everyday sounds. *J Exp Psychol Human Percept Perform* 1993;**19**:250–67.
- 4 Wogalter MS, Young SL. Behavioural compliance to voice and print warnings. *Ergonomics* 1991;**34**:78–89.
- 5 Morris RW, Montano SR. Response times to visual and auditory alarms during anaesthesia. *Anaesth Intensive Care* 1996;**24**:682–4.
- 6 Donchin Y, Seagull FJ. The hostile environment of the intensive care unit. *Curr Opin Crit Care* 2002;**8**:316–20.
- 7 Momtahan KL, Hetu R, Tansley BW. Audibility and identification of auditory alarms in the operating room and intensive care unit. *Ergonomics* 1993;**36**:1159–76.
- 8 Lower MC, Patterson RD, Rood GM, *et al*. *The design and production of auditory warnings for helicopters. 1: The Sea King*, Research Report No.AC527A. Southampton, UK: Institute of Sound and Vibration, 1986.
- 9 Kestin IG, Miller BR, Lockhard H. Auditory alarms during anaesthesia monitoring. *Anaesthesiology* 1988;**69**:106–9.
- 10 Block FE, Schaaf C. Auditory alarms during anaesthesia monitoring with an integrated monitoring system. *Int J Clin Monit Comput* 1996;**13**:81–4.
- 11 Block FE, Nuutinen L, Ballast B. Optimisation of alarms: a study on alarm limits, alarm sounds, and false alarms, intended to reduce annoyance. *J Clin Monit Comput* 1999;**15**:75–83.
- 12 Bliss JP, Gilson RD, Deaton JE. Human probability matching behaviour in response to alarms of varying reliability. *Ergonomics* 1995;**38**:2300–12.
- 13 Bliss JP, Dunn MC. Behavioural implications of alarm mistrust as a function of task workload. *Ergonomics* 2000;**43**:1283–300.
- 14 Westenskow DR, Orr JA, Simon FH, *et al*. Intelligent alarms reduce anaesthesiologists’ response time to critical faults. *Anaesthesiology* 1992;**77**:1074–9.
- 15 Schoenberg R, Sands DZ, Safran C. Making ICU alarms meaningful: a comparison of traditional versus trend-based algorithms. *J Am Med Inform Assoc Suppl* 1999;**379**–83.
- 16 Bolsona JF, Altaba C, Maull E, *et al*. Are auditory warnings in the intensive care unit properly adjusted? *J Adv Nurs* 2001;**35**:402–6.
- 17 Beydon L. Do away with alarms or make them intelligent? *Ann Fr Reanim* 2001;**20**:667–8.
- 18 Deutsch D. Delayed pitch comparisons and the principle of proximity. *Percept Psychophys* 1978;**23**:227–30.

- 19 **Patterson RD**, Edworthy J, Shailer MJ, *et al.* *Alarm sounds for medical equipment in intensive care areas and operating theatres*, Report No. AC598. Southampton, UK: Institute of Sound and Vibration Research, 1986.
- 20 **Stanford LM**, McIntyre JWR, Hogan JT. Audible alarm signals for anaesthesia monitoring equipment. *Int J Clin Monit Comput* 1985;1:251–6.
- 21 **Oberli C**, Urzua J, Saez C, *et al.* An expert system for monitor alarm integration. *J Clin Monit Comput* 1999;15:29–35.
- 22 **Edworthy J**, Loxley S, Dennis ID. Improving auditory warning design: relationship between auditory warning sound parameters and perceived urgency. *Hum Factors* 1991;33:205–31.
- 23 **Hellier EJ**, Edworthy J, Dennis ID. Improving auditory warning design: quantifying and predicting the effects of different warning parameters on perceived urgency. *Hum Factors* 1993;35:693–706.
- 24 **Haas EC**, Edworthy J. Designing urgency into auditory warnings using pitch, speed and loudness. *IEE Comput Control J* 1996;7:193–8.
- 25 **Belz SM**, Robinson GS, Casali JG. A new class of auditory signals for complex systems: auditory icons. *Hum Factors* 1999;41:608–18.
- 26 **Edworthy J**. Cognitive compatibility and warning design. *Int J Cogn Ergon* 1997;1:193–209.
- 27 **Blachowicz J**, Wojcicki J, Ladyzynski P, *et al.* A novel approach to the alarms system for monitoring of the patient state in cardiac intensive care units. In: Carson E, Salzeider E, eds. *Modelling and Control in Biomedical Systems*. Pergamon Press, 2000:253–6.
- 28 **Kerr JH**, Hayes B. An 'alarming' situation in the intensive therapy unit. *Intensive Care Med* 1983;9:103.
- 29 **Kerr JH**. Warning devices. *Br J Anaesth* 1985;57:696–708.
- 30 **International Standards Organisation**. *Anaesthesia and respiratory care alarms*, International Standards Organisation, 1992.
- 31 **Hedley-White J**. Helping to ameliorate a healthcare crisis: general requirements and guidelines for the application of alarms in medicine. *ISO Bull* April 2003.

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