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Learning three sets of alarms for the same medical functions: A perspective on the difficulty of learning alarms specified in an international standard

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ABSTRACT

Three sets of eight alarms supporting eight functions specified in an international medical equipment standard (IEC 60601-1-8) were tested for learnability using non-anaesthetist participants. One set consisted of the tonal alarms specified in the standard. A second set consisted of a set of abstract alarms randomly selected from a database of abstract alarm sounds held by the authors. A third set of alarms was designed as indirect metaphors of the functions. Participants were presented with the alarms and then asked to identify them across ten blocks of eight trials. The results indicated a significant difference in learnability across the three sets of alarms. The indirect metaphors were learned significantly better than both other sets of alarms, and the randomly selected abstract alarms were learned significantly better than the alarms specified in the standard. The results suggest therefore that there are more readily learnable possible designs than those proposed in the standard. The use of auditory icons in particular should be given serious consideration as potential alarms for this application.

1. Introduction

In order for an alarm to be effective, it needs to have a number of key features. Some of these features are embedded in the reliability of the technology itself. Many medical alarms have extremely high false alarm rates (Edworthy, 2013; Keller et al., 2011; Siebig et al., 2010; Talley et al., 2011). This is a problem, because studies show that people respond to alarms in proportion to the actual, or perceived, false alarm rate. Alarms which are 90% reliable are responded to just over 90% of the time, whereas alarms which are 10% reliable are responded to just over 10% of the time (Bliss et al., 1995; Bliss and Dunn, 2000; Bliss and Acton, 2003). Currently, the high rate of false alarms is number one on the list of the US Emergency Care Research Institute's list of top ten hazards (ECRI, 2009) and is a major patient safety issue. Other important components of alarm effectiveness are more closely related to the design of the alarms themselves and are the domain of ergonomics. One key element of good practice in design of alarms is that they should be relatively easy to learn both in terms of the problem they are signalling (their referent), and any response which should follow. In practice, this has not always been achieved and in this paper we highlight a particular set of alarms which has caused considerable consternation in the medical domain. We compare that set of alarms with other possible designs and outline the design issues which are central to ease of learning of alarms. The work presented here demonstrates how the research evidence base available on alarm learning can be applied to a problem which has already been identified; that is, the difficulty which the learning of the alarms associated with IEC 60601-1-8 seems to present. Though the research evidence is available in the literature, and similar studies have been carried out in other areas (for example, Perry et al., 2007) it has not been directly applied to this pressing problem, which is causing consternation amongst groups concerned with the standard and how it might be developed. For example, the Association for the Advancement of Medical Instrumentation, a large not-for-profit US organisation involved with patient safety, has adopted this problem and its solution as one of its mission goals (AAMI alarms steering group, June 4th 2013, Long Beach, California).

The alarms associated with an important standard, IEC (International Electrotechnical Commission) standard 60601-1-8 'Medical electrical equipment – Part 1–8: general requirements for basic safety and essential performance' (IEC, 2006) have caused concern because studies show that they are difficult to learn, they appear to be easier to learn by people with musical training (which is not the norm in the work environment) and the mnemonics/lyrics suggested for aiding learning do not appear to help. The alarms were

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designed for the following eight functions: Oxygen, ventilation, temperature, cardiac, perfusion, drug delivery, equipment or supply failure and finally a general alarm sound. The general alarm sound is intended for use as an alternative to one or more of the specific alarms. In practice, manufacturers often use the general alarm when they are using only a single alarm on a product. The alarms are tonal in nature (they manifest themselves as short 'melodies') and they are constructed through the use of short pulses of sound made into longer bursts of sound. There is a medium and a high priority version of each alarm. All of the medium priority alarms consist of three regularly-spaced pulses of sound lasting between one and 2 s and all of the high priority alarms consist of five pulses, the first three pulses as in the medium priority alarm, with two additional pulses after a short pause. The pulses of the high priority alarms are shorter and are played closer together, meaning that they have a greater sense of urgency (Edworthy et al., 1991) and are not necessarily longer in total length than the medium priority alarms. All of the alarms therefore have the same rhythm, only differentiable by their different pitch patterns, or melodies.

The current IEC 60601-1-8 alarms were designed ('composed' in the words of the proposers (Block et al., 2000)) as a well-intentioned move to rationalise and improve these alarms by imbuing the signals with a sufficient level of acoustic appropriateness in order to avoid masking and to aid detection, which was achieved. The aspects of the design which are more salient to the listener have been the main cause for concern. Each of the alarms have the same temporal pattern (rhythm) but are differentiated in terms of their precise tonal patterns. The origin of the shared temporal pattern is of some interest: because the rhythm of the general alarm had been adopted and developed through an earlier, similar standard (ISO 9703-2), it was decided that this 'three plus two' rhythm should be the basis of the new standard. Hence, all of the alarms designated in IEC 60601-1-8 have the same rhythmic pattern. Some attempt at guiding the listener as to the meaning of the alarms was also proposed. For example, the 'temperature' alarm consists of rising tones in order to indicate a slow rise, and the equipment failure alarm contained a large drop in pitch to indicate loss of energy. At a later point, mnemonics, or lyrics, were suggested in order to make the learnability of those alarms easier. For example, the lyrics 'tem-pra-ture – a-larm' was suggested for the high priority temperature alarm.

The pitch patterns of the alarms are shown in Table 1. A priori, the high level of acoustic similarity between the alarms would suggest that they would be difficult to learn and research has confirmed this. Sanderson et al. (2006) asked non-anaesthetist participants to learn the eight alarms indicated in the IEC standard. They found that over two lengthy learning sessions, fewer than 30% of the participants successfully learned the alarms. Participants also did not perform better (indeed they performed worse) when they were encouraged to use the mnemonics/lyrics. Also, although participants rated the high priority alarms as being more urgent than the lower priority alarms, they responded more accurately and faster to the medium priority (3-pulse) alarms. Wee and Sanderson (2008) found similar results when testing nurses, with only one nurse successfully learning all alarms over the two testing sessions. Again, mnemonics/lyrics did not help (though their use did narrow the number of confusions found between the alarms), and the medium priority again produced faster and more accurate response times. Nurses with musical training (defined as at least one year of formal training on a musical instrument) performed significantly better on the task than those without.

Sanderson et al.'s work amply demonstrates that the existing IEC alarms are difficult to learn. Other studies also demonstrate that tonal, abstract alarms are difficult to learn. Studies by Ulfvengren (2003) and Leung et al. (1997) demonstrate that the nature of the sound used as an alarm significantly affects its learnability. Both showed that speech alarms are the easiest to learn, followed closely by auditory icons (where there is some link between the sound and its function). Abstract alarms, where there is no recognisable association between alarm and function, are by far the hardest to learn.

The degree of association between the alarm sound and its referent appears to be a key element in ease of learnability (Perry et al., 2007). Keller and Stevens (2004) and Petocz et al. (2008) have explored the dimensions of sound-referent relationships and argue that it is the strength of the sound-referent relationship which governs the ease with which an alarm sound can be learnt. Importantly, sound-referent relationships can be either naturally-occurring or learnt. For example, the use of a skidding tyre to mean 'brake' is rapidly learned (Belz et al., 1999; Graham, 1999) because there is a natural relationship between the two. Strong relationships between sounds and referents can be developed also through repeated association, even when there is no intrinsic link. Language is the best example of this learned association.

Research into the IEC alarms has tended to focus on problems with learning the specified set, rather than focussing on better sets of alarms for the same functions, even though the standard allows for alternatives. It is likely that there are many possible design alternatives which could be applied to the design of new IEC alarms. In the following study we therefore compare three sets of potential alarms to support the functions of IEC 60601-1-8. Three sets of eight sounds were designed to signal the eight functions associated with the IEC 60601-1-8 hazards. Participants were repeatedly played each of the eight alarms from one of the three sets and asked to identify which of the eight referents was being signalled by the alarm currently being presented. The three alarm sets were as follows: the IEC set (in high priority form), a set of abstract, but more varied, alarms for the same functions, and a set of auditory icons (explicitly, indirect metaphorical icons). We chose to use indirect metaphorical icons (Keller and Stevens, 2004) because we wanted to test a set of auditory icons which might be plausible for actual use in the medical environment. Direct representations (or indeed audifications, which are basically amplifications of the actual sounds made) of the referents themselves possess characteristics which would make them difficult to implement in the actual working environment, partly because it would be difficult to amplify them to a level which would make them reliably audible in a noisy ward, and partly because some of the IEC hazards (for example, temperature) have no obvious sound which could be amplified. Indirect metaphorical icons, where the sound in some way represents the function but is a sound not heard in that environment, were selected on the basis both that acoustically more robust sounds could be developed and that by virtue of being indirect metaphors, there is little chance that the sounds would occur in the medical environment otherwise. These features are important in practical terms.

Table 1
IEC alarms.

Function	Tonal structure of alarm
General	c c c – c c
Cardiac	c e g – g C
Artificial perfusion	c f# c – c f#
Ventilation	c a f – a f
Oxygen	C b a – g f
Temperature	c d e – f g
Drug delivery	C d g – C d
Equipment/power failure	C c c – C c

Note: 'c' represents middle c on the piano (262 Hz), 'C' the octave above (524 Hz). All other tones lie somewhere between the two on a musical scale.