http://dx.doi.org/10.14236/ewic/HCI2018.228

Soundscaping: Sound, meaning and vision in healthcare alarm systems

Siné McDougall
Bournemouth University
Fern Barrow
Bournemouth BH12 5BB.
smcdougall@bournemouth.ac.uk

Judy Edworthy
Plymouth University
Drake Circus
Devon PL4 8AA.
j.edworthy@plymouth.ac.uk

Sound alarm systems are designed to help healthcare professionals make critical decisions, affecting the wellbeing of patients. Given the ease with which we deal with the complex and disparate sounds that occur in our day-to-day environment, the difficulties users encounter when dealing with auditory alarms in healthcare systems seem remarkable. This paper examines the reasons underpinning the difficulties experienced with current alarms and explores how alarm systems might be improved resulting in less confusion and better established user mental models. The implications for medical decision making are discussed.

Auditory alarms. Health care. Meaning and mental models. Eye tracking.

1. INTRODUCTION

Recognising sounds in our environment, from a frog croaking to the reassuring whirr of our computer when we switch it on, occurs effortlessly. The sound landscape that is created by groups of environmental sounds informs our understanding as events unfold. For example, 'night-time camping' sounds might include frogs croaking, crickets chirping, a tent zip, yawning, and a mosquito buzzing (Marcell, Malatonos, Leahy & Comeaux, 2007). Recent neuroscientific evidence suggests that processing of environmental sounds forms the basis for building rich mental models and results from neural processing across a network of brain areas including those associated with the localization of sounds in space, semantic processing of non-verbal sounds, accessing word meaning, and the 'imageability' of sounds (Sharda & Singh, 2012; Tomasino et al., 2015).

Given the ease with which we richly process and utilise environmental sounds, it is remarkable that sets of auditory alarms do not convey information more effectively. The consequences of ineffective alarms have been well documented and particular concern has been expressed with respect to alarm systems on medical devices; the number of deaths associated with alarm-related events led the United States Joint Commission to issue a Sentinel Event Alert in 2011 for what was seen as a frequent and persistent problem.

2. ACCESSING MEANING FROM ALARMS

Part of the problem is that trigger points for alarms are inappropriately set leading to high false alarm rates which are likely to provoke alarm fatigue (Edworthy & Hellier, 2005; Wickens et al., 2009). It is also to do with the way that the sounds have been designed, making the meaning they are intended to convey difficult to access or easy to confuse with other similar alarm sounds. This is important because research has consistently demonstrated that auditory signals with a close relationship between the sound and referent (meaning) are learned more easily, especially if they use sound-based metaphors with the real world (Atyeo & Sanderson, 2015; Edworthy et al., 2013; Isherwood & McKeown, 2016). Sound-based metaphors are typically caricatures of environ-mental sounds such as coughing to indicate 'leaking gas' or the sound of a heartbeat to indicate that 'cardiovascular function needs to be checked' (Stevens et al., 2009; Edworthy et al., 2014). Medical alarm sounds, in contrast, tend to be either tonal sequences or beeps, buzzers and pings. Here, the alarms are not related in any systematic way to the meaning that they are meant to represent. The lack of access of tonal auditory alarms to meaning makes it difficult to build working mental models of the alarm system which are needed for effective responding.

An example of this issue is IEC 60601-1-8 (2012), the current global standard for medical alarms which specifies the acoustic properties and qualities of the alarms to be used in a great deal of detail. Alarms from the current standard are employed in wards as well as operating theatres and alarms need to be understood easily by staff with different roles and levels of experience. The alarms are carefully specified in such a way as to achieve a reasonable level of audibility, resistance to masking, and their construction is based on

Proceedings of British HCI 2018. Belfast, UK.

known psychoacoustic principles. However, the alarms are tonal in nature – very much like short melodies – and so bear no obvious relation to their intended meaning. The alarms are also very similar acoustically, making them difficult to discriminate between. Worryingly, evidence to date shows that nursing staff are not any better at recognising these alarms in comparison to undergraduates - only nurses with musical training were able to distinguish sounds within the set more effectively (Lacherez, Seah & Sanderson, 2007; Sanderson et al., 2006). Being unable to discriminate sounds leads to confusion and lack of direct access to meaning results in users' relying on rote paired-associate learning once the sounds have been discriminated.

The problems associated with the existing IEC 60601-1-8 alarms represents the perfect storm of learning and retaining alarm sounds: first, there is no association between the alarm and its referent and secondly, the set of sounds themselves are remarkably homogeneous. Both are likely to contribute to the problem of accessing meaning from sound alarms. This is of particular importance when critical healthcare decisions need to be made in an effective and timely fashion.

3. LINKING SOUND, MEANING, AND VISION

The symbiotic relationship between language and appropriate visual cues in allowing individuals to develop appropriate mental representations was established in a classic experiment by Bransford and Johnson (1972). Participants' recall and comprehension of a taped passage was measured when they were given appropriate visual contextual information, partial information or no information. A shortened version of the passage is as follows:-

> 'If the balloons popped, the sound wouldn't be able to carry since everything would be too far away from the correct floor. The whole operation depends on a steady flow of electricity, a break in the middle of the wire would cause problems. Of course, the fellow could shout, but the human voice is not loud enough to carry that far. An additional problem is that a string could break on the instrument. Then there could be no accompaniment to the message. It is clear that the best situation would involve less distance. Then there would be fewer potential problems. …'

Without appropriate visual contextual cues (see Figure 1) this text is extremely difficult to understand but could be easily understood by participants when supporting visual information was provided. We argue that the same holds true for alarm sounds.

Recent research shows how examining the combination of sound and visual cues can be carefully considered to improve our understanding of interface usability and the mental models and cognitive processing employed by users. Kodappully et al. (2016) examined where human error in monitoring complex process plants was most likely to occur. Eye tracking was a key measure used to investigate the cognitive processes when operators were dealing with simulated scenarios in which alarms were triggered in complex process plants. A series of alarm sounds along with visual information on the control displays alerted operators to imbalances in the systems which required action. Eye gaze data which examined how long operators spent examining the key parts of the interface in response to the alarm showed 'a strong correlation … between AOI [area of interest] measures and the orientation, diagnosis, and execution steps' carried out while dealing with potential imbalances in the system. On this basis they suggested that eye tracking could be used to assess how operators use decision support systems in real-life control rooms and assess novices' learning when dealing with alarms.

Dehais et al. (2014) used eye tracking to examine 'inattentional deafness', the lack of response to auditory alerts (see Edworthy et al., 2018 for similar findings). Typically lack of response is attributed to pilots choosing to ignore warnings due to decision biases, hearing issues, or conscious risk taking. They asked pilots to deal with higher and lower workload scenarios in which a triple-chime auditory alarm sounded to indicate failure of the landing gear along with appropriate warnings on the visual landing gear indicator. They found that under higher workload pilots were more likely to report not hearing the triple-chime alarm, were less likely to glance at the landing-gear indicator immediately after the alarm, and less likely to carry out appropriate manoeuvres to deal with the landing-gear failure. As a result of their combined use of alarms and eye gaze data, they were able to establish inattentional deafness under high workload conditions as a cognitive phenomenon that is critical for air safety and recommend changes to the alarm system to avoid this problem.

Both Dehais et al. (2014) and Kodappully et al. (2016) have demonstrated importance of assessing the combination of visual cues and alarms sounds, neither of these studies deals with the combination of sound, meaning and vision in a healthcare situation or with the issues of discriminability and meaningfulness highlighted earlier. Recent work carried out in our laboratory brought these themes together. Participants were presented with alarm sets which differed systematically in the extent to which the alarms used real world metaphors (e.g. the sound of a tone vs a heartbeat sound to indicate 'check cardiovascular function'). They also differed in the extent to which alarms could be discriminated from one another within the set (similar vs different alarm sounds).

Participants' eye movements were tracked as they learned to associate alarm sounds with the appropriate equipment in an operating theatre scene. Participants were asked to click on the equipment associated with the alarms they heard over a series of learning trials in order to mimic – to some extent at least - healthcare staff responding to alarms appropriately. In addition to the accuracy of their responses, relatedness ratings were also used to assess the formation of meaningful relationships between alarms and equipment. Relatedness ratings and scan path data showed that participants quickly built effective mental models of alarm-referent relationships when alarms could be easily discriminated from one another and when the alarms sound used real world metaphors. Confusion and poor understanding of the meaning of the resulted for those learning alarm tones and this was compounded when the tones were acoustically similar and difficult to discriminate from to one another. Participants' lack of understanding of acoustically similar alarms was also reflected in their scan paths which were more complex indicating their confusion about which piece of equipment the alarm was associated with. They took longer to fixate on the correct pieces of equipment. These findings led us to the conclusion that alarms need to be discriminable and meaningful to allow users to build appropriate links between the alarm sounds they are hearing and the visual cues before them in a manner which is very similar to that originally discovered by Bransford & Johnson in 1972.

4. DISCUSSION & CONCLUSIONS

A central tenet of interface design is the provision of appropriate visual cues in interfaces in order to facilitate meaningful and effective interaction and attending to pertinent visual cues is an important part of medical interfaces and decision-making (Al-Moteri et al., 2017). It is therefore not surprising that eye-tracking is being increasingly used as a tool to assess the usability of healthcare equipment (Asan & Yang, 2015). We have argued that many of the reported instances where alarms are ignored arise may be because alarms it is difficult to match sound alarms meaningfully with visual cues in the healthcare environment.

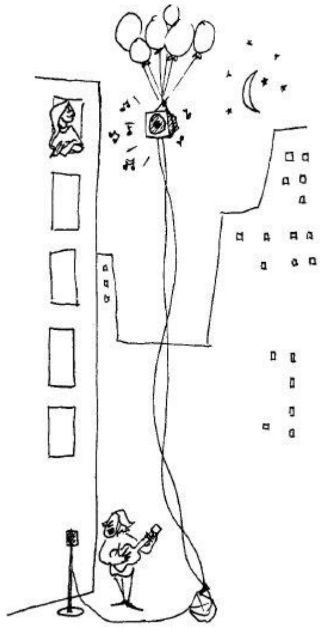

Table 1: *Appropriate context picture facilitating passage comprehension (Bransford & Johnson, 1972)*

A new way of thinking about alarms may be to create appropriate 'sound landscapes' that fit well with their context of use and with users' existing mental models. Alarm sets may be best thought of as 'sound events … sequences of closely grouped and temporally related environmental sounds that tell a story' (Marcell et al., 2007, p.561). Creating appropriate sound landscapes using groups of sounds will mean that users are effectively informed as events unfold. As everyday users of language and environmental sound, it should be possible to create sets of sounds which may be as superficially disparate as the sounds of frogs croaking, tent zips, yawning, and mosquitoes buzzing associated with night-time camping but, by being relevant, the sounds will allow us to understand the nature of the whole sound event and act upon it 'achieving the greatest possible cognitive effect for the smallest possible processing effort' (Sperber & Wilson, 1986, p. viii).

5. REFERENCES

Al-Moteri, M.O., Symmons, M., Plummer, V. & Cooper, S. (2017). Eye tracking to investigate cue processing in medical decision-making: A scoping review. Computers in Human Behavior, 66, 52-66.

Asan, O. & Yang, U. (2015). Using eye trackers for usability evaluation of health information technology: A systematic literature review. JMIR Human Factors, doi:10.2196/humanfactors.4062.

Atyeo, J. & Sanderson, P.M. (2015). Comparison of the identification and ease of use of two alarm sound sets by critical and cute care nurses with little or no music training: A laboratory study. Anaesthesia, 70, 7, 818-827.

Bransford, J.D. & Johnson, M.K. (1972). Context-ual prerequisites for understanding: Some investigations of comprehension and recall. Journal of Verbal Learning and Verbal Behavior, 11, 717-726.

Dehais, FR., Causse, M., Vachon, F., Régis, N., Menant, E. & Tremblay, S. (2014). Failure to detect critical auditory alerts in the cockpit: Evidence for inattentional deafness. Human Factors, 56, 631-644.

Edworthy, J. & Hellier, E. (2005). Fewer but better auditory alarms will improve patient safety. BMJ Quality & Safety, 14, 212-215.

Edworthy, J., Page, R., Hibbard, A., Kyle, S., Ratnage, P., & Claydon, S. (2014). Learning three sets of alarms for the same medical functions: a perspective on the difficulty of learning alarms specified in an international standard. Applied Ergonomics, 45(5), 1291-1296.

Edworthy, J., Reid, S., Peel, K., Lock S., William, J., Newbury, C, Foster, J. & Farrington, M. (2018). The impact of workload on the ability to localize audible alarms. Applied Ergonomics, 72, 88-93.

International Electrotechnical Commission (2012). IEC 60601-1-8: Medical electrical equipment– General requirements, tests and guidance for alarm systems in medical electrical equipment and medical electrical systems. IEC, Geneva, Switzerland.

Isherwood, S.J. & McKeown, D. (2017). Semantic congruency of auditory warnings. Ergonomics, 60, 1014-1023. doi: 10.1080/00140139.2016.1237677.

Kodappully, M., Srinivasan, B., Srinivasan, R. (2016). Towards predicting human error: Eye gaze analysis for identification of cognitive steps performed by control room operators. Journal of Loss Prevention in the Process Industries, 42, 35-46.

Lacherez, P., Seah, E. L., & Sanderson, P. (2007). Overlapping melodic alarms are almost indiscriminable. Human Factors: The Journal of the Human Factors and Ergonomics Society, 49, 637-645.

Marcell, M., Malatanos, M., Leary, C. & Comeaux, C. (2007). Identifying, rating, and remembering environmental sound events. Behavioural Research Methods, 39, 561-569.

Sanderson, P. M., Wee, A., & Lacherez, P. (2006). Learnability and discriminability of melodic medical equipment alarms. Anaesthesia, 61, 142-147.

Sharda, M. & Singh, N.C. (2012). Auditory perception of natural sound categories – an fMRI study. Neuroscience, 214, 49-56.

Sperber, D. & Wilson, D. (1986). Relevance: Communication and Cognition. Blackwell: Oxford.

Stevens, C., Brennan, D. & Petocz, A. & Howell, C. (2009). Designing informative warning signals: Effects of indicator type, modality, and task domain on recognition speed and accuracy. Advances in Cognitive Psychology, 5, 42-48.

Tomasino, B., Canderan, C., Marin, D., Maieron, M., Gremese, M., D'Agostini, S., Fabbro, F., & Skrap, M. (2015). Identifying environmental sounds: A multimodal mapping study. Frontiers in Human Neuroscience, 9, Article 567. doi: 10.3389/fnhum.2015.00567.

Wickens, C.D., Rice, S., Keller, D., Huchins, S., Hughes, J. & Clayton, K. (2009). Fase alerts in air traffic control conflict alerting system: Is there a 'cry wolf' effect? Human Factors, 51, 446-462.