Institution: University of Plymouth

Unit of Assessment: UoA4

Title of case study: Improving alarms in rail transport and healthcare

1. Summary of the impact

Many adverse outcomes, including deaths, have been attributed to alarms. Historically, alarms have fallen short of their potential to contribute to safe working because the psychological aspects of understanding and responding to alarms were overlooked. Without careful consideration of the relationship between the acoustic elements embodied in their design, and their relationship to both understanding and timely response, alarms by themselves are no guarantee of safety. Edworthy and Hellier have a long record of influential work on the study of the relationship between alarm design, understanding, and response. This involvement has led to changes in guidelines, international standards, the development of best practice documents, and new products in both healthcare and the rail industry in both the UK and worldwide, particularly the US.

2. Underpinning research

Professor Judy Edworthy has worked at the School of Psychology continuously since 1985 and has followed a programme of research on alarms as indicated below. Dr Elizabeth Hellier was a PhD student and Research Fellow in the School of Psychology from 1988-1994, returning as lecturer in 2000, and has worked jointly with Edworthy on this programme. Various other individuals named in the publications have been employed to work with Edworthy and Hellier on the basis of external funding obtained for this work. Ms Loxley was a research assistant 1993-4. Mr Weedon and Ms Walters acted as research assistants 1999-2001. Ms Aldrich was a PhD student 2001-4 and a research fellow 2004-5. Dr Austin Adams (James Cook University, Singapore) collaborated with Edworthy and Hellier on parts of this programme as an overseas visitor.

When alarms are used in the work environment, one of the key, early issues reported by users was that the urgency of the alarm did not match the urgency of the situation it signals. Edworthy and Hellier sought to clarify in great detail the relationship between alarm design parameters and perceived urgency during the period 1993-2002. For example, an early paper demonstrated that the relationship between the key acoustic parameters of pulse rate, frequency, harmonic structure, repetition, and the psychological construct of 'perceived urgency' can be successfully described in considerable detail using Steven's Power Law, which can then be applied to generate alarm sounds and other sounds which are predictably more or less urgent from one another (Hellier, Edworthy and Dennis, 1993). After 2002 this work was applied to speech alarms where it was demonstrated that human speakers use those same acoustic parameters to indicate different levels of urgency. The findings were subsequently used to synthesise speech warnings that are reliably judged to differ in urgency according to pre-experiment predictions (Hellier, Edworthy, Weedon, Walters and Adams, 2002). Further work extended these findings by comparing real and synthesized voices in terms of their urgency, appropriateness and believability. Here, earlier findings were largely replicated, and it was also found that semantic (word meaning) effects were stronger for synthesised speech than for real speech, and that female speakers produced a greater range of urgency responses from listeners than did male speakers. (Edworthy, Hellier, Walters, Crowther and Clift-Matthews, 2003).

Within the same programme, between 1995 and 2006 the research also considered perceptual and cognitive associations between changes in acoustic parameters and possible interpretations other than 'urgent' which might be useful in safety-critical situations; for example, meanings such as 'safe', 'controlled' and 'rising' (Edworthy, Hellier and Hards, 1995). This work was extended in a later study (Edworthy, Hellier, Aldrich and Loxley, 2004) that showed similar findings to Edworthy et al. (1995) but also, importantly, demonstrated that perception of change in meaning is asymmetrical when increases in acoustic parameters are compared with equivalent decreases. For example, a specific rise in pitch may lead to an increase in urgency rating of 'x' whereas a fall of the same amount does not lead to a corresponding decrease of 'x'. This is important for design purposes as it restricts the use of continuous sound (sonification) as a viable alternative to discrete alarms and therefore emphasises the importance of alarms research in this area of application.

From 2005 onwards, the group has also explored the nature of auditory similarity and difference among sounds and has demonstrated the extent to which key acoustic parameters underpin judgements of similarity between familiar and unfamiliar sounds (Aldrich, Hellier and Edworthy, 2009). This work has been extended more recently in applied, design papers

demonstrating how knowledge of the factors which underpin acoustic similarity and difference can be used to design sets of alarms which are readily discriminable.

3. References to the research

Peer-reviewed publications:

Hellier, E., Edworthy, J. & Dennis, I. (1993). Improving Auditory Warning Design: Quantifying and Predicting the Effects of Different Warning Parameters on Perceived Urgency. *Human Factors 35*, 693-706. DOI: 10.1177/001872089303500408 Citations: 117. Impact factor 2011: 1.2; 5-year IF 2.1; Ranked 7/16 by IF in 'Ergonomics'. Ranked 5/16 by Eigenfactor (JCR)

Hellier, E., Edworthy, J., Weedon, B., Walters, K. & Adams, A. (2002). The Perceived Urgency of Speech Warnings 1: Semantics vs Acoustics. *Human Factors*, *44*, 1-17. DOI: 10.1518/0018720024494810 Citations: 41. Impact factor 2011: 1.2; 5-year IF 2.1; Ranked 7/16 by IF in 'Ergonomics' Ranked 5/16 by Eigenfactor (JCR)

Edworthy, J., Hellier, E. J., Walters, K., Crowther, M. & Clift-Matthews, W. (2003) Acoustic, semantic and phonetic effects in spoken warning signal words. *Applied Cognitive Psychology, 17*, 915-933. DOI: 10.1002/acp.927 Citations: 21. Impact factor 2011: 1.667; 5-year IF 1.964; IF ranked 45/84 in 'Psychology, Experimental'; Eigen factor ranked 30/84 (JCR))

Edworthy, J., Hellier, E., & Hards, R. (1995) The semantic associations of acoustic parameters commonly used in the design of auditory information and warning signals. *Ergonomics, 38*, 11, 2341-61. DOI:10.1080/00140139508925272 Citations: 36. Impact factor 2011 1.409; 5-year IF 1.620; IF ranked 3/16 in 'Ergonomics'; Eigenfactor ranked 2/16 (JCR))

Edworthy, J., Hellier, E., Aldrich, K. & Loxley, S. (2004). Designing Trend Monitoring Sounds for Helicopters: Methodological issues and an application. *Journal of Experimental Psychology: Applied*, *10*, 203-218. DOI: 10.1037/1076-898X.10.4.203 Citations: 12. Impact factor 2011 1.754; 5-year IF 2.597; IF ranked 23/73 in 'Psychology, Applied'; eigenfactor ranked 24/73 (JCR)

Aldrich, K., Hellier, E., & Edworthy, J. (2009) What determines auditory similarity? The effect of stimulus group and methodology. *Quarterly Journal of Experimental Psychology*, *62*, 62-83 DOI:10.1080/17470210701814451 Citations: 8. Impact factor 2011 1.964; 5-year IF 2.354; IF ranked 38/84 in 'Psychology, Experimental'; Eigenfactor ranked 14/84 (JCR)

Grants

EPSRC: 'Behavioural responses to speech and non-speech warnings' £150,000 (Edworthy and Hellier, 1999-2001)

Rail Safety Standards Board: 'Human Factors Guide to Managing Alarms and Alerts in the Rail Industry' £140,000 (Edworthy and Hellier, 2006-7)

Rail Safety & Standards Board: Alarms and alerts guidance and evaluation tool sound library £19,000 (Edworthy and Hellier, 2008-9)

NHS Connecting for Health: 'Efficacy of prompts and alerts in eprescribing' £80,000 (Edworthy and Hellier, 2009-10)

Rail Safety and Standards Board, UK: The design of Train Protection Warning System (TPWS) alarms in support of Railway Group Standard RT/GE8030 (Issue 3). £10,000 (Edworthy)

4. Details of the impact

The two areas in which this work has had its impact are 1) Rail Safety and 2) Healthcare Alarms.

1) Rail

Edworthy and Hellier were awarded a series of competitive tender contracts concerning alarms by the Rail Safety and Standards Board (RSSB), a not-for-profit company owned by major stakeholders in the railway industry. The RSSB had identified a number of problems in terms of how rail alarms were implemented and designed, and wished to address these problems using our

expertise and research findings. These outputs, in their entirety, represent a comprehensive set of tools and guidance for use by professionals involved in both new implementations (signalling, new rolling stock and so on) and the retrofit of old systems and installations across the rail industry. The outputs from these projects are: a good practice guide to the implementation of alarms and alerts containing significant elements directly following from our research such as urgency mapping, alarm confusability, considerations when implementing speech warnings, and other important elements underpinned by our research [1]; an alerts and alarms assessment tool, which is a broad-ranging, interactive tool (including all of the underpinning research mentioned above) for users to assess the extent to which alarms might conform with good practice, giving guidance as to how evidence-based research might will produce improvements in alarm systems [2]; practical observations of real train cabs indicating how alarms might be improved [3]; and studies testing the learnability and discriminability of modified and improved alarms for rail use. The group also developed a sound library to support the alerts and alarms assessment tool, which embodies many aspects of our research (for example, how to manipulate the perceived urgency of an alarm; and the relative advantages and disadvantages of different types of sounds as alarms). The dates and copyrights of the documents listed in Section 5 confirm that these outputs were published from 2009 onwards, and authorship is clearly attributed to the group in most cases. The work was led by Edworthy and Hellier, with input from Professor Jan Noyes (University of Bristol, who collaborated on a report on the potential use of speech warnings); Bill Gall (Human Factors consultant, who collaborated on collating and interpreting railway standards); and Greenstreet Berman (a Human Factors consultancy, who produced the final working version of the alarms and alerts tool in terms of improving its organisation, layout and usability – Edworthy and Hellier produced the original concept, scope and content).

The RSSB has presented the alarms and alerts assessment tool at a number of industry and policy forums [4]. The beneficiaries of these tools are companies concerned with rail activities such as Network Rail, the Association of Train Manufacturers (ATOC), regulators (such as the RSSB and the Health and Safety Executive) in general terms. More specifically, beneficiaries include human factors specialists (of which there are many in the rail industry), train designers, alarms and alarm-related equipment hardware manufacturers, and train manufacturing companies such as Bombardier. Bombardier has used the tool and the sound library to: develop call-for-assistance alarms; to generate evidence-based design principles in order to scope alarm design protocols and principles; and to evaluate the efficacy of their existing alarms [5].

In 2010-11, Edworthy was invited by the RSSB to design and document a new Train Protection and Warning System (TPWS) based on the principles encapsulated in our evidence-based guidance, particularly the need to avoid confusion with other alarms in the train cab and to design an alarm with appropriate attention-getting and urgency characteristics. The TPWS is the system which alerts the driver to take action (because of, for example, a red signal ahead, or over-speeding), before the brakes are automatically applied [6]. This alarm now supports Railway Group Standard GE/RT 8030 Issue 4, the new national standard for TPWS alarms for all trains operating in the UK since 2012. The documentation of the new standard indicates that use of this alarm is mandatory [7].

Health

Here, the beneficiaries of our work are policy-makers, medical instrument manufacturers and medical alarm designers. Our research has filtered through to medical standards and alarm policy debate, particularly in the US, where ‘alarm fatigue’ has been identified as a major patient safety issue by medical safety organisations such as the Association for the Advancement of Medical Instrumentation (AAMI), the Emergency Care Research Institute (ECRI), and the Joint Commission. These groups convened an alarms summit in Herndon, Virginia in October 2011. Edworthy was invited to contribute to this as part of an acoustics group which wrote a white paper on alarm fatigue [8].

An important global standard, IEC 60601-1-8 8 (‘Medical electrical equipment: General requirements for basic safety and essential performance’) is causing great concern for those people whom it affects (a broad range of policy-makers, regulators, medical instrument companies and safety organisations) because the alarms specified in that standard are known to be problematic in their design. As a consequence, Edworthy was invited to join the Association for the Advancement of Medical Instrumentation’s IEC 60601-1-8 alarms committee instigated since the

alarms summit) and alarms steering group in 2012. The AAMI IEC 60601-1-8 committee has direct links with the IEC 60101-1-8 standards committee (they share the same Co-Chair) who is keen to redesign the alarms supporting this standard as there are known problems with them [9], which will feed into subsequent versions of the standard.

The principles of perceived urgency in sound (a main thrust of our research) have already been embraced in the new version of this standard (IEC 60601-1-8, 2013) independently of committee activity, through direct knowledge of our research. Within the main body of the standard there is much reference to the matching of the urgency of the audible alarms to medical priorities. How the standard indicates this might be achieved relies exclusively on our research findings. Annex D of this standard (p.83), which provides guidance for the construction of alarm signals and the manipulation of acoustic urgency, lists the composite findings of our research into perceived urgency. It begins: 'Parameters that affect the perceived urgency of a burst of sound include the inter-pulse interval, the number of repeating bursts, the rhythm of the pulses in the burst, changes in intra-pulse duration within a single burst, the pitch contour, pitch range and musical structure'. Annex D goes on to display a table of the attributes of perceived urgency, which has been taken directly from Edworthy and Adams (1996) Warning Design: A Research Prospective, p.155, which summarises the known perceived urgency principles available at that time [10].

5. Sources to corroborate the impact (indicative maximum of 10 references)
The superscripts in Section 4 refer to the corroborating evidence listed below:

1. RSSB Alarms and alerts Good Practice Guide : http://www.rssb.c.uk/SiteCollectionDocuments/pdf/reports/research/T326_GoodPracticeGuide.pdf. Authorship attributed to the group and the larger research team at the beginning of the document
2. RSSB Alarms and alerts toolkit: http://www.rssb.co.uk/SiteCollectionDocuments/pdf/research-toolkits/T326/index.html. This website acknowledges the Plymouth group's involvement in the toolkit
3. RSSB Train cab observations: http://www.rssb.co.uk/SiteCollectionDocuments/pdf/reports/research/T326_appendices_final-pdf. Authorship attributed to the group and the larger research team at the beginning of the document
4. Human Factors group, Rail Safety and Standards Board, UK (corroborating email)
5. Research Manager, Bombardier Transportation, Derby, UK (corroborating email)
6. Train Protection and Warning System audible alarm standard design report: http://www.rssb.co.uk/SiteCollectionDocuments/pdf/reports/research/T326_rpt_final-pdf Authorship attributed to Edworthy
7. Railway Group Standard GE/RT8030 Issue Four Requirements document: Appendix G contains Guidance on audible alarms taken from the good practice guide and alarms and alerts toolkit (as generated by the group). Appendix H contains the audible alerts designed in (4) with the indication that 'The content of this appendix is mandatory' http://www.rgsonline.co.uk/Railway_Group_Standards/Control%20Command%20and%20Signalling/Railway%20Group%20Standards/GERT8030%20Iss%204.pdf
8. www.aami.org/meetings/summits/alarms/Materials/Alarm_fatigue_white_paper.pdf. This is the white paper produced by the acoustics group invited to the alarms summit, where Edworthy is an author
9. http://aamiblog.org/2012/12/07/dave-osborn-sounding-the-alarm-at-standards-week/ The Co-chair of the AAMI Alarms Committee and the Co-convenor of the ISO/IEC Joint Working Group on alarms records the issue of badly-designed alarms currently supporting IEC 60601-1-8 and indicates moves by AAMI, together with Edworthy, to redesign them
10. IEC 60601-1-8 'Medical electrical equipment – Parts 1-8: General requirements for basic safety and essential performance – Collateral standard -: General requirements, tests and guidance for alarm systems in medical electrical equipment and medical electrical systems (published by the International Electrotechnical Commission). p. 83Guidance for auditory alarm signals describes many of the group's recommendations concerning urgency and contains a table taken from Edworthy and Adams (1996) *Warning Design: A Research Prospective,* London: Taylor & Francis, p. 155