Alarm fatigue in the perception of medical soundscapes

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Summary

This paper sketches out the rationale behind our plans to gather empirical data in investigating the problems associated with "alarm fatigue". Whereas most approaches to alarm fatigue focus solely on reducing the number of alarms, based on a premise of inferred causality, we envision a methodological approach which allows for a positive description of the manifold of problems associated with alarm fatigue based on evidence-based knowledge of both the subjective and the objective sound environment. This leads us, first, to deconstruct the alarm fatigue hypothesis and show its shortcomings. Secondly, we present the possibilities that our method of data collection will have for understanding both the issues concerned with alarm fatigue, and those connected with the current soundscape of alarm-rich environments.

1. Introduction

During the last decades alarm hazards have been increasingly recognised as a major problem in the medical world. ECRI (Emergency Care Research Institute, US) recently announced its 2015 Top 10 Health Technology Hazards list. The top priority - for the fourth year in a row - was clinical alarm hazards. This fact demonstrates very well the severity of the problems associated with alarms at hospitals. Though alarm-related incidents are believed to be underreported [1], it is well-documented that patient safety is compromised as a consequence of unnecessary time spent in alarm management (i.e. nurses responding to alarms) and dealing with the unexpected and unwanted effects of bad alarm implementation. For instance, more than 500 patient deaths related to alarm management have been reported to the U.S. Food and Drug Administration (FDA) during a four-year period [2].

In almost all safety-critical areas where workload is also high, alarms tend to proliferate. This is true of many types of transport, nuclear power control, and medicine. Audible alarms are intended as an effective safety measure as they can attract attention when the operator is engaged in other tasks, looking somewhere other than the target of interest, or is visually occupied in some other way. However, because they are so useful, audible alarms tend to be overused and start to present unwanted problems because of their overuse.

Traditionally, alarms were based on a few sounds which were produced by mechanical means (such as bells, klaxons and so on) and were associated with problems such as being too loud, too insistent and likely to interfere with communication at the very time when they are most necessary [3]. With the advent of digital technology it has been possible to broaden the scope of alarm design, making it possible to have almost any sound as an audible alarm. Researchers have designed and tested alarms which are similar to real-world sounds, often referred to as 'auditory icons' [4], [5], as well as the more traditional 'beep' and 'ping'-style sounds with which we are familiar [6]. This research shows some advantages for particular types of alarm sounds for particular environments.

One aspect which has not been given much consideration is the influence of whole alarm sets on alarm effectiveness - for example that of heterogeneity within a set of alarms, though it has been demonstrated that a more heterogeneous set of alarms is easier to learn and remember than a more homogeneous set [7]. Generally, the efficacy of alarms is considered within a very small framework which may include only a very small number of alarms, or a set of alarms. However, in the workplace alarms are heard along with all other auditory stimuli and so those methodologies which take into account this broader soundscape should be able to inform research and design issues in a more ecologically valid way. We cannot really know the advantages and disadvantages of the different types of approaches to alarm design without knowing how they will fit into and influence the broader soundscape.

Recently, some studies [8], [9] have started to consider the broader soundscape of those environments where alarms figure predominantly. This ecological approach is likely to help researchers understand the broader perceptual landscape in which alarm sounds figure. In this paper we present a methodological approach which will allow us detailed insight into the soundscape of a medical area – an Intensive Care Unit – whilst also addressing an increasingly important work issue in the medical world, that of alarm fatigue.

2. Alarm fatigue

In the literature and in debates on alarm hazards alarm fatigue has been predominantly discussed by American clinicians and researchers, as the medical world in Europe and other parts of the world, despite fighting with the same problems, are only beginning to adopt the term. Alarm fatigue is often proposed as a significant *cause* of failing alarm management among nurses. Cvach [10] has deemed alarm fatigue a national problem in the US, and at the Clinical Alarm Safety Symposium (CASS) in November 2014 alarm fatigue was the main theme. One of the most essential take-home messages from CASS was that the general problem of alarm fatigue has still not been cracked, despite the joint efforts of powerful American organisations like AAMI, FDA, The Joint Commission, and ECRI to improve alarm system management (sparked by the Medical Device Alarm Summit in 2011).

So far, the challenge of alarm fatigue has largely been thought of as a matter of reducing the number of alarms. This approach is reasonable given that the number of alarms has multiplied in recent years [1]. Nevertheless, there seem to be fundamental problems with how people operate in environments in which there are multiple alarms potentially active, and how they prioritise their behaviour. It has not been addressed adequately how these problems relate to or constitute part of the concept of alarm fatigue.

Alarm fatigue is commonly defined as the *desensitisation* to alarm sounds due to an excessive number of alarms [10], [11]. However, different - yet somewhat related - definitions are found in the literature. Sendelbach and Funk [1] define alarm fatigue as *sensory overload* due to an excessive number of alarms, which *can* result in desensitisation (p. 378). Rappleye [12] describes alarm fatigue as a phenomenon occurring when nurses "tune out noise" (whatever that means). The *cry wolf* effect (i.e. a repeated series of false/non-actionable alarms which eventually causes people to ignore the important alarms) is also often mentioned in discussions on alarm fatigue. Whereas the principle itself is clear, the resulting behaviours being reported in the medical world are different: nurses may ignore alarms, turn off alarms, turn down the volume of alarms, be desensitised to alarms, and so on.

Alarm fatigue, thus, is utilised as an umbrella term to designate a series of problems related to the medical world with staff not responding to alarms the way they are intended to. What is problematic about this multi-utilisation of the concept is that the exact causes for the known problems get blurred. Consider the following example of reasoning about alarm fatigue: "Nurses not recalling hearing low heart rate alarms were indicative of alarm fatigue which contributed to the patient's death" [11, p. 2]. Desensitisation - a phenomenon that has been demonstrated in the psychological literature [13] - could very well be the problem here. However, the problem could also be *masking*, a well-known and well-defined psychoacoustic problem [14], or *change deafness* [15]. It could be *confusability* - a problem that has been extensively discussed in the alarm design literature [6], [7]. Or it could be a matter of *selective attention* [16] - the case being, for instance, that the nurse was occupied thinking about something important. Or it could be something else.

In other words, it is very unclear what alarm fatigue in fact *is*. It seems to be the logic of the alarm fatigue hypothesis that many of the reported problems are only symptoms - i.e. indicatives - of some causing factor. For lack of more elaborate explanations this causing factor is called alarm fatigue. Thus, the concept seems more to be an untested hypothesis (i.e. an inferred analytical construct) about some correlation between a high number of sounding alarms and some problems in nurses' abilities to respond accordingly to medical protocols, rather than being a qualitatively defined construct coming out of evidence-based research.

3. Our approach

We are currently conducting an alarm study within the Intensive Care Unit at a local hospital. We describe here our approach to the planning of the study, and discuss the kind of results we are expecting to obtain.

Whereas the few studies on hospital soundscapes which have been carried out tend to focus either on objective properties of the environment, for instance the number of alarms [11], or properties of the subjective experience [17], our study integrates the characteristics of the behaviour and subjective experience of alarm users with quantitative and qualitative characteristics of the objective soundscape.

We are using Lahlou's [18] Subjective Evidence-Based Ethnography (SEBE) technique. SEBE is essentially a method for collecting empirical data on subjective experience and is based on the combination of three techniques which also form three overall stages as follows.

Stage 1 involves audio-visual data collection. Here the purpose is to capture 1st person, 2nd person, and 3rd person perspectives of the alarm milieu by audio-visual recordings. By 1st person perspective we mean data that convey information about how the individual nurse experiences the alarm milieu. By 2nd person perspective we mean data that convey information about how nurses interact (with other members of staff or patients). By 3rd person perspective we mean data that convey information about the "objective soundscape" (i.e. recordings of the different alarms from different positions in the hospital space) and the location, movement and reactions of nurses. To capture 1st and 2nd person perspectives of the alarm milieu we are using miniature audio-visual recording equipment, worn by the participating nurses. The 3rd person perspective is being collected via the use of camcorders and field recorders. Camcorders are placed at strategic locations in the ward so that they capture the activities going on in relevant parts of the ward (mainly nurses' room location and movement). Field recorders are placed at the alarm sound sources in the ward together with decibel level recorders. Currently we are collecting this data, using a small number of nurses across a number of 12-hour shifts. Once the auditory and visual recordings have been collated they will be subject to detailed analysis and coding of events, alarms, visual information, interactions between individuals and so on.

Stage 2 involves conducting semi-structured interviews with each of the participating nurses. The interviews are centred around selected excerpts from the personal 1st person audio-visual recordings of the individual nurse. The rationale is that the nurses, by reviewing their work experiences, are able to contribute with introspective insights that clarify what is "going on" in the selected situations. Furthermore, we need to make sure to what extent our observations and inferences are in accordance with their perceptions of their experiences.

In stage 3 we will meet briefly with the nurses to formulate our interpretations of the output of the interviews (the results of stage 2) and discuss the final interpretations.

4. Results

The study is exploratory in the sense that no specific a priori hypothesis is guiding the research design. As we try to establish a methodologically triangulated foundation for capturing the complexity of alarm fatigue, we will be looking very broadly for signs of alarm fatigue in relation to the perception of a hospital soundscape.

One source of inspiration to guide our search for signs of alarm fatigue "outside the box" is Hutchins' [19] take on cognitive anthropology, which aims to study human cognition in its natural habitat, or, as he calls it, "naturally occurring culturally constituted human activity" [p. xiii]. In this framework cognition is regarded as *distributed* across multiple agents and their environment. That is, an adequate description of cognitive processes does not only pertain to the neuropsychological setup of an individual, but rather to the dynamics of ecological systems.

In our case it is relevant to be aware of the ecological nature of what has been referred to as *alarm compliance* in the alarm literature [20], that is, decisions made by subjects on how to react when they hear alarms going off. To be able to account for the ecology of such decisions we will synchronise data showing how nurses experience and behave in their work environment with data showing their movement patterns and interactions (i.e. audio-visual material from a 1st-person, 2nd-person, and 3rd-person perspective).

Such a synchronisation allow us to build a matrix with a diverse set of analytical strata (e.g. physical, temporal, social as suggested by Mackrill et al. [9]) that can be investigated for significant influences on soundscape perception of the individual nurses. For instance if we look at the physical level (e.g., environment), it is reasonable to believe that certain areas in the ward are more exposed to alarms than others, or more acoustically rich and complex than others. This would mean that nurses spending much time in designated "busy areas" would be more inclined to feeling fatigued than others. By tracking how much time nurses spend in different areas of the ward - and recording what they hear and see at different times and places - we will know not only how many and which alarms they have experienced in course of their work shift, but also *exactly where* they heard the alarms. This knowledge alone could be used to make a map of designated weak spots of soundscape perception, which could support efforts to redesign the acoustics of the ward interior or the way in which the alarm sounds are distributed. For our purposes, however, knowing the spatial-temporal trajectory of the nurses is only a first step towards understanding the challenges involved in attending "rightfully" (i.e. in accordance with medical protocols) to the hospital soundscape. A second step is to account for the in-situ perceptual cues that are interfering with nurses' alarm awareness. From observations that we made during a preliminary visit at the care unit it is clear that the ward is abundant with consequential sounds (in addition to the intentional sounds of which alarm sounds constitute the majority) (see van Egmond [21] for a definition of consequential and intentional sounds). A few minutes' observation gave an indication of how many sources of consequential sounds nurses are in fact exposed to. Among the sources were: trolleys, footsteps, speak, bins closing, medical devices, curtains dividing rooms, entrance doors, napkin holders, cupboards, cleaning sounds, patient-interaction (e.g. change of electrodes, washing), television, crying, laughing, and telecommunication devices.

The analyses of our recordings and interviews with the nurses should indicate to what extent the consequential sounds play a role in the emergence of alarm fatigue. It is likely that they pose psychoacoustic challenges, for instance in terms of masking. It could also be the case that the consequential sounds are fatiguing the auditory system of the nurses simply by virtue of their presence (just like the alarm sounds).

Aside from identifying and analysing the acoustic cues that potentially interfere with alarm awareness, a challenge in our method is to identify interfering cues in other modalities. Our audio-visual miniature equipment will allow us to characterise (1) what nurses *look at*, (2) what they *talk about*, and (3) their *actions*, which we consider to be three important variables with influence on how alarms are perceived.

We will have visual tracking in the sense that we have records of the visual field of the nurses supplemented by their own account of what they were attending to in particular instances. This will allow us to make a categorisation of their visual attentional field during a work shift in the hospital environment. Once we know what categories of objects (e.g. monitors, equipment, documents, faces) occupy their visual attention, we will be able to check for correlations between reduced alarm awareness and specific visual attention patterns.

We are also tracking how much nurses talk and what they talk about, in order to see how the cognitive workload of their verbal communication impacts on alarm awareness. Perceptual masking is usually discussed in the context of sound reception rather than sound production. In our case it is likely that sound production (i.e. speech) constitutes a great part of the total sound activities that nurses engage in during a work shift. Our recordings and the follow-up interviews allow us to explore how self-produced sounds integrate with alarm sounds in nurses' soundscape perception. It will be relevant to see whether there are clear differences between alarm responses in talking vs. non-talking conditions, and if so, whether their own verbal communication in any sense could be masking the alarms and thereby contribute to the missing alarm responses. Here it is not only relevant *if* nurses are talking but also *what* they are talking about. Following Dickerson and Gaston's [15] discussion on different types of masking, answers as to whether the mere act of talking or only the content of a conversation accounts for any failures to respond can be investigated as matters of *detection masking* or *informational masking* correspondingly. If we think the other way around about causality, it will also be relevant to see to what extent alarm sounds are disturbing the verbal communication of nurses and thereby are contributing to fatigue.

Finally, the data we get from the audio-visual recordings allow us to categorise the actions of nurses (in addition to their verbal communication).

A tool of potentially great relevance, as employed by Edworthy et al. [22], is the measurement of alarms co-occuring with work activities. Here again the idea is to see how the cognitive workload of their activities impact on alarm awareness. As with visual and verbal tracking, the explanations we get here will have to arise in the interplay between introspective insights from the nurses when re-living their work day on video (stage 2 in our method) and our grounded theories, which among other things will feed from well-known psychoacoustic constructs.

All in all, these three analytical enquiries (i.e. vision, verbal communication, and actions) may lead us to propose a set of quite diverse explanations (i.e. grounded theories) of causes for alarm fatigue.

Another vein of analytical enquiry that will be facilitated by the work described above is how individual differences in perception have implications for alarm fatigue. So far individual differences in alarm perception has not been explored very much, but research in other areas of auditory perception show that people perceive and interpret sounds differently. For instance, Gusev and Schapkin [23] found that extraversion, impulsivity, neuroticism and achievement motivation were related with specific performances and reaction times in prolonged signal detection tasks. Another line of studies in auditory bistability perception [24] has demonstrated stable individual differences in terms of perceptual switching patterns. Findings like these may be very relevant to how individual nurses cope with the complex environment. The fact that we will capture episodes in which the same alarms are heard by different nurses should constitute a fertile ground for studying individual perceptual differences in natural settings. Many factors will of course influence how individuals differ in their perception of the alarms. From preliminary investigations we know that several nurses have hearing deficits to varying degrees. Furthermore, the group of participating nurses will reflect a diversity in work experience. Ultimately, the important thing is not to draw a line between extrinsic and intrinsic factors, but rather to identify what factors in both domains are contributing to the problems of alarm perception. As part of the interviews we will have an opportunity to present selected alarms (or constellations of alarms) to our subjects, should we find it necessary to be reassured that some response observed in the data has in fact to do with the individual's perceptual abilities rather than extrinsic factors.

In addition to the subjective analysis of nurses' perspective, sketched out above, our method will allow us to describe in detail the objective soundscape of the ward. Drew et al. [11] carried out a study in which the total number of alarms in one unit were registered, which is useful if one has the intention to reduce the number of alarms. For our purposes we are more interested in knowing more about the combination of alarms (and the resulting complexity of the sonic environment) the individual nurses are exposed to during a work shift. One important measurement to be made here is the number of simultaneous alarms (that nurses are exposed to) as a function of total time during one work shift (fig. 1). Knowing how often nurses are exposed to how many and which combination of alarms will give us an indication of which aspects of temporal structure contribute to alarm fatigue. For example we want to know if it is the sum of all alarms that constitute the problem, or whether it is momentary coincidences of many alarms that really matters.

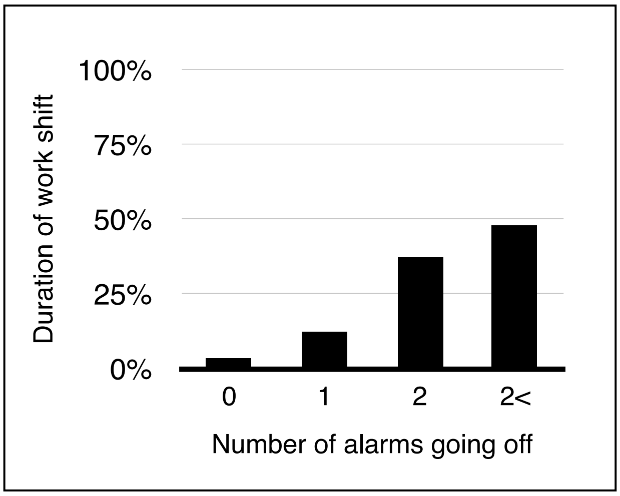

Figure 1. Clusters of simultaneous alarms as a function of the total duration of a work shift (example made for illustrative purposes).

By documenting the actual sound of different combinations of alarms, we will (for future studies) have a good foundation for exploring inter-alarm fits in terms of identification difficulties. Optimal temporal fits has been a theme in guidelines for alarm design [25], but still needs to be studied systematically. The data we collect in this study will allow us to apply a variety of known psychoacoustic methods (e.g. masking, confusion, similarity between sounds) to its analysis and understanding. Ultimately, this will allow us to determine how auditory streaming of the soundscape might occur.

Our combination of subjective and objective approaches to understanding the soundscape of the ICU means that we will be able to explore how different occurrences and degrees of acoustic complexity correspond to different aspects of subjective awareness. For our purposes a continuum of alarm awareness could be structured around four analytical landmarks that we consider important. These are the extent to which nurses are (a) exposed to alarms, (b) aware of the alarm exposure, (c) aware of the meaning of the alarms, and (d) respond appropriately to the alarms.

What is important about presenting this kind of continuum of alarm awareness is not so much the number of levels of differentiation as the fact that these diverse aspects of nurses' alarm perception are found within one and the same context (i.e. with the same set of alarms experienced within the same temporal frame under the same ecological conditions). Though we will be able to use formal psychoacoustic modelling to further understand the objective constraints of the acoustic environment and the problems that might ensue, our main goal is to provide an *integrated* understanding of the problems associated with alarm fatigue that extends beyond acoustic issues.

Acknowledgement

This project has been funded by the European Union (FP7 – People – 2013 – ITN).

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