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# Alarm fatigue in the ward

## An acoustical problem?

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## Abstract

*This article addresses the need of including acoustical perspectives in the debate on alarm fatigue within the healthcare domain. We show how conceptualisations and proposed solutions to alarm fatigue are unequally distributed across what could be called the 'alarm chain': a generic model of the core structural elements and dynamic relations that constitute any alarm scenario. A focal point in the alarm chain – the 'alarm mediation cleft' – seems to divide the alarm fatigue literature from the segment of the alarm literature that deals with auditory alarm design. The current healthcare discourse on alarm fatigue is centred around the 'pre-mediated alarm phase', which has the consequence of an unfortunate dichotomous approach to the functionality of sound. We address some shortcomings of this approach and outline some methodological implications and potentials of searching for signs of alarm fatigue in the 'post-mediated alarm phase'.*

## Introduction

The use of alarm sound to prevent patients from dying or being seriously harmed has become an integral part of modern intensive care in hospitals. Over the last decades the use of medical outsourcing of decision-making regarding clinical intervention in the form of alarm systems has increased significantly. Nowadays critically ill patients are being monitored by an arsenal of medical devices, many of which will trigger a sound once a predefined threshold value is exceeded. This has resulted not only in a proliferation in the total number of alarm sounds, but also in the number of different alarm sounds (Borowski et al., 2011; Kerr & Hayes, 1983).

In the medical world it is believed that the proliferation of alarm sounds, notably from non-actionable alarms, has the negative consequence that clinical staff gets desensitised to alarms, which may lead to inadequate responses to alarms of critical importance in caregiving. This problem has become known as 'alarm fatigue' (e.g. Cvach, 2012; Sendelbach & Funk, 2013; Horkan, 2014). Reports of sentinel events related to alarms started appearing already in the 1970s (Funk et al., 2014), and clinicians have talked about alarm fatigue at least since the 1980s (Cvach, personal communication). Not until recently, however, has the problem been recognised as significant in the more formal medical discourse. In the last decade the nursing literature has seen a boom of publications on alarm fatigue. This development goes hand in hand with the increased awareness of other alarm-related issues. Since 2008 the Emergency Care Research Institute (ECRI) has published an annual Top 10 Health Technology Hazards Report in which alarm-related hazards have been consistently rated as one of the top priorities, and recent clinical alarms summits (2011 and 2014) have initiated collaborations among the major associations in the US


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healthcare system to reach the vision of 'a world in which, by 2017, no patient will be harmed by adverse alarm events' (AAMI, 2011, p. 5).

In the healthcare literature the vast majority of accounts of the nature of alarm fatigue and plausible methods for solving the problem are remarkably homogeneous. The generic definition that emerges out of the literature (in our words, i.e. our attempt to summarise many of the definitions encountered with one best fitting sentence) could be stated like this:

> Alarm fatigue refers to the situation in which (sheer) exposure to a high number of (non-actionable) alarms causes an alarm user to be desensitised/sensorily overloaded/overwhelmed, which might in turn cause the user to not respond adequately to alarms (e.g. miss or display delayed responses, ignore alarms, turn off alarms).

In the following we will refer to this definition as the 'uniform narrative'. It is a narrative in the sense that it is used by many healthcare professionals as a call to arms to act on patient safety, but it is also a *theory* in the sense that it asserts a causal relationship between exposure to non-actionable alarms and desensitisation (the term for the effect that is used most widely). The theory seems to be grounded in the behaviouristic doctrine, in that instances of alarm fatigue are *inferred* by observations of missed responses to alarm sounds without taking into consideration the mental processes of the member of clinical staff whose behaviour was observed. That is, the construct of alarm fatigue is rooted in a third person perspective rather than a first person perspective, what in anthropological terms is known, respectively, as *etic* versus *emic* approaches to the understanding of human behaviour.

A fundamental problem, to which we direct our attention in the present discussion, is to clarify what it is about an alarm situation that is fatiguing according to the uniform narrative, which should provide a foundation for discussing what other factors could be fatiguing (i.e. factors that are not taken into account in the current discourse).

## The conceptual problem of alarm research

Dealing with the subject of 'alarm' in an overall manner is problematic for several reasons. To mention a few: There is no single, unified research field, and different academic disciplines (e.g. engineering, psychology, acoustics, cognitive ergonomics) deal with the subject in different ways. As a consequence, 'the literature' (if it makes sense to speak of one) is scattered across academic and professional communities that are adhering to different ontological, epistemological and theoretical assumptions. Moreover, there is a multitude of definitions present in the literature (for a review, see Wallin, 2009) which are not necessarily conflicting, but which add to the problem of confusion in terminology (McNeer et al., 2007). One source of confusion


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relates to how 'alarm' is distinguished from related terms such as 'warning' and 'alert'. For instance, Haas and Edworthy (2006) use alarm as a generic term for all sounds that attract attention, whereas they define auditory warnings as 'sounds that are designed specifically to attract attention, but also to provide additional information and support' (p. 190). Stanton (1994), on the other hand, does not make this distinction in stating that 'the role of the alarm is to give warning of impeding danger' (p. 6). Another source of confusion is that 'alarm' is used to designate different elements that characterise an alarm event, typically either a stimulus, a medium or a response (Stanton, 1994; Wallin, 2009). According to Stanton (1994):

> [T]he main problem with definitions of the term 'alarm' is that they tend to concentrate on only one or a restricted range of the qualities. Thus there is need to consider the term further, to un-pack and understand the nature of an 'alarm'. (p. 3)

Only a few efforts have been made to characterise the nature of alarm in a broader sense. Notably Stanton (1994), Wallin (2009) and Wallin et al. (2012) have contributed with meta-analytic approaches to the problem of alarm conceptualisation.

The ambiguity of the notion of alarm is not only conceptual, but extends into a discussion of the nature of alarm-related problems, like alarm fatigue. We are in favour of a pragmatic stance to the conceptual problem of alarm, appreciating that any alarm model highlights *selected* features of the specific kind of event we call 'alarm', and that the highlighted features and the level of abstraction of a model reveal more about the *person* and *agenda* behind the conceptualisation of the event than the event itself. As our purpose is to demonstrate how the problem of alarm fatigue is reflected at the level of conceptual structure we present here an ad hoc alarm model (Figure 1) with a series of elements that allow us to point out how different strands of alarm research diverge in their conceptualisation of the nature of the alarm problem. Thus, the elements of the model are based on problems encountered in a critical reading of the literature. For instance, a pertinent question is to what extent the alarm *signal* and the alarm *medium* can be separated in the causal explanation of alarm fatigue. This and other important analytical distinctions (to be discussed in the following) are illustrated in Figure 1. The model is inspired by Wallin's (2009) model of the 'alarm chain', a demonstration of how 'alarms are transformed and managed in a chain of abstractions' (p. 462).

Our model has the same underlying metaphorical structure (a chain of interconnected links), but highlights different features. It has four structural components and four dynamic relations that, in principle, should be necessary conditions for any alarm event to take place (however, our agenda here is not to formalise a generic alarm definition, but to present a model that applies to how alarms are used in hospitals). As depicted in Figure 1, the model presents an *object of monitored activity* (1), for instance a patient's organism, which is *monitored* (2) by some *monitoring intel-*


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*ligence* (3). If the activity of (1) changes significantly, as predefined by (3), an *alarm signal* (4) will be triggered to materialise the alarm state of (1) in the form of an *alarm medium* (5), for instance a sound. After being *exposed* (6) to (5) the *intended alarm user* (7) should display *compliance behaviour* (8) and intervene on (1).

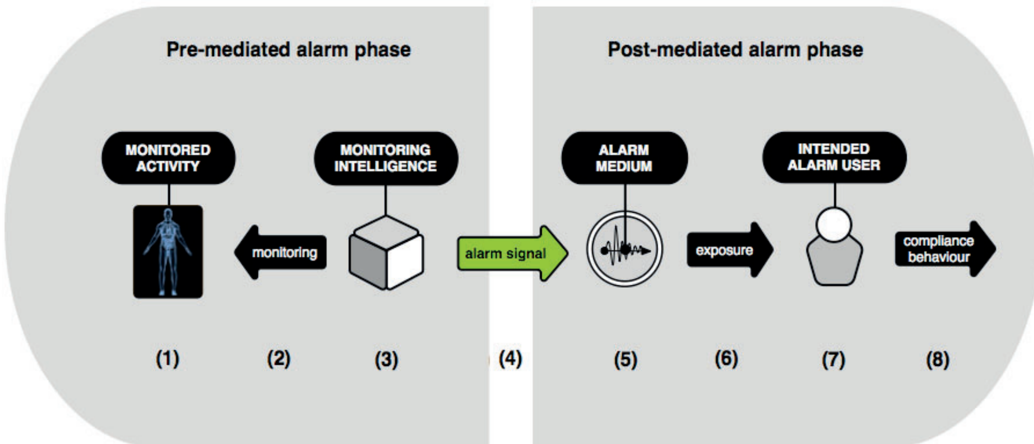


*Figure 1: The alarm chain. Schematic representation of central structural components and dynamic relations in an alarm event. The space that divides the pre-mediated alarm phase and the post-mediated alarm phase represents the 'alarm mediation cleft'.*

For analytical convenience we refer to the part of the overall cognitive structure of the alarm event in which the transition from the signal to the medium takes place as the 'alarm mediation cleft'. The use of the term 'cleft' is motivated by the observation that the discourse on alarm fatigue is predominantly focussed on the part of the alarm chain comprised by elements 1-4 and thereby separated from the latter part of the alarm chain. We refer to the two subsets of cognitive structure that are depicted on each side of the alarm mediation cleft in Figure 1 as the pre-mediated alarm phase and the post-mediated alarm phase.

## Alarm fatigue in the pre-mediated alarm phase

The argument that the discourse on alarm fatigue is centred around the 'pre-mediated alarm phase' is based on the identification of three themes that recurrently resonate in the literature: (I) the cry wolf effect, (II) the reductive approach to solving the problem of alarm fatigue and (III) the conceptualisation of sound as noise.

In many publications on alarm fatigue (e.g. Bailey, 2015; Cvach et al., 2014; Purbaugh, 2014; Sendelbach & Funk, 2013) the so-called cry wolf effect is used to explain the essence of alarm fatigue. The notion derives from Aesop's fable about the shep-

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herd boy who repeatedly leads the villagers into believing that a wolf is attacking the sheep by calling for help. Because of the repeated exposure to false alarms the villagers stop trusting the boy and do not react to his call on the day that a wolf actually attacks the sheep.

By this rationale clinicians' exposure to non-actionable alarms is believed to increase the likelihood that they will not respond appropriately to an alarm sound in the case of a critical event. Behavioural evidence suggests that people's response rate to some alarm sounds is indeed likely to be influenced by their previous experience of the false positive rate of the alarm (Cvach, 2012). The psychological mechanism at play in the cry wolf effect has been discussed in the alarm and warning literature by use of different terms such as 'probability matching' (Bailey, 2015; Bliss, Gilson, & Deaton, 1995) and 'cost-benefit analysis' (Edworthy & Adams, 1996). A lack of responding to alarms can also be conceptualised through the framework of 'habituation' (Thompson & Spencer, 1966), a core learning theory phenomenon whereby a response to a stimulus reduces each time that stimulus is presented, if there is no consequence to that stimulus (as in the case of an alarm being presented with no clinical or other problem to deal with).

Whatever we call this effect it seems that we are dealing with a higher order 'cognitive' processing of sound. In Aesop's fable the cry wolf effect relates to the villagers' (lacking) appraisal of the *meaning(s)* of the word 'wolf' (a four-legged carnivore, dangerous animal etc.), not the acoustic features of the pronounced word (the registering of the latter is, of course, a precondition of the former, but with regard to this effect not the essential thing). Accordingly, for clinicians to display a behaviour that could be interpreted as the cry wolf effect would require not only the mere registering of a sound, but also the understanding of the meaning of the sound and then, in addition, a choice to *disobey* the compliance behaviour that is expected from them according to the clinical protocol.

The cry wolf effect, however, seems to capture the problem of alarm fatigue only partially, at least judged by how the problem is defined in the discourse of the uniform narrative. The act of *deliberate* disobedience is implicitly suggested in some definitions of alarm fatigue in the way the problem is phrased: Clinicians are 'ignoring alarms' (Parke et al., 2015; Purbaugh, 2014) or 'turning off alarms' (Nix, 2015). But other definitions propose symptoms of alarm fatigue that (judged by the choice of phrasing) cannot be explained by the cry wolf effect. For instance, symptoms like 'missed alarms' (Funk et al., 2014; Sendelbach & Funk, 2013) and 'failures to notice an alarm sound' (McKinney, 2014; Whalen et al., 2014) do not suggest any voluntary acts of disobedience. Yet other accounts render it difficult to know whether or not some (lacking) compliance behaviour was voluntary or involuntary, for instance by describing the outcome of alarm fatigue as 'delayed responses' (Funk et al., 2014; Horkan, 2014; Jones, 2014).


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The fact that the cry wolf effect is widely used to explain the problem of alarm fatigue is perhaps one of the reasons that a *reduction of non-actionable alarms* stands out as the most feasible solution to the problem of alarm fatigue in the literature. A great variety of clinical actions to reduce the number of non-actionable alarms have been initiated during the last decade (for reviews, see e.g. Cvach, 2012; Purbaugh, 2014; Sendelbach & Funk, 2013). Many of these initiatives have be successful, and they are indeed important to reduce the likelihood that clinicians will disobey an alarm and thereby fail to respond appropriately to a critical event due to the cry wolf effect.

Nevertheless, it is important to realise that 'alarm' in this way of thinking refers to the alarm *signal* without regard to the attributes of the alarm *medium*. This obviously has consequences for how research on alarm fatigue is conducted. In a recent field study Drew et al. (2014) treated the total number of auditory *and* visual alarms as one unified variable without any further discussion of the effect of the distribution between auditory and visual alarms, let alone the attributes of the different kinds of auditory and visual alarms. Whereas the attributes of the alarm medium were not necessarily considered unimportant in this study, other studies of alarm fatigue are quite deliberately downplaying the role of the alarm medium. For instance, several publications point out the 'sheer' number of alarms as the cause of alarm fatigue (e.g. Funk et al., 2014; Jones, 2014; Purbaugh, 2014).

The uniform narrative thus comes with a rather explicit neglect of alarm sound as a semiotic resource. In the American healthcare discourse sound is literally conceived of as noise. At the Clinical Alarm Safety Symposium 2014 'sound' and 'noise' were used interchangeably by presenters from all corners of the healthcare system – researchers, institutional leaders, clinicians, device manufacturers – and also in literature there is often no differentiation made. Some publications (e.g. Rockstroh, Sykes, & Barach, 2015) do not even mention sound, but mention only noise.

The notion of noise has various meanings, the most common of which seems to be *unpleasant sound* (Sangild, 2002, p. 6). The characterisation of alarm sound as noise is reasonable, having in mind that alarm sound is in its very essence a designed disturbance. It should have what Vannini et al. (2010) call 'elocutionary power', that is, 'a particularly vivid, striking, evocative, and attention-grabbing [property]' (p. 334) that calls for some sort of compliance behaviour (Edworthy & Adams, 1996). It means, nevertheless, that a somewhat paradoxical rationale is underlying the medical alarm philosophy as such.

The medical outsourcing paradigm that was initiated more than three decades ago has (partly) replaced the monitoring intelligence (element 3 in Figure 1) of a human (i.e. a clinician) with the artificial monitoring intelligence of a machine. This has resulted in a structure of 'double monitoring': The clinician is monitoring a selection of machinery that is monitoring a patient's internal organism. In



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order to facilitate the clinician's monitoring of the computerised monitoring system the machines are given predefined algorithm thresholds, the crossing of which will trigger some 'noise'. That is, the price for outsourcing to a computer some of the responsibility of detecting potentially critical events in the patient's organism is to accept the exposure to unpleasant sound and, more importantly, to be responsive to this sound.

Alarm fatigue, thus, can be construed as an outcome of a misbalance in the tension between two counterforces: an initiative to *decrease* cognitive load (the outsourcing of monitoring to medical devices) and the consequence of this initiative (added alarm sound) which *increases* cognitive load. This way of construing the problem suggests a point of equilibrium, or a point of optimal alarm efficiency; there should, in theory, be an optimal number of alarm sounds.

To the knowledge of the authors no one has yet proposed any optimal number of alarm sounds other than 'as few as possible' (Costa, Scotto, & Pereira, 2010; Rothenburg, 2009). There is a significant body of research demonstrating that people's ability to learn and remember alarm sounds is limited, often restricted to single numbers, which at first glance may be thought of as evidence that the numbers of alarms used should be small, and that there is an optimal number (e.g. Lacherez, Seah, & Sanderson, 2007; Patterson, 1982; Sanderson, Wee, & Lacherez, 2006; Wee & Sanderson, 2008). However, this finding relates to abstract alarm sounds, which are also known to be more difficult to learn than other types of sounds (Edworthy et al., 2014; Ulfvengren, 2003). The issue as to whether there is an optimal number of alarms depends, of course, also on the understanding of the situations which trigger those alarms, and the optimality of that process, and not only the qualities of the audible alarms themselves, which can be improved upon. Obviously, since the aim is to get rid of the non-actionable alarms only, not to cut down the number of actionable alarms (i.e. true alarms), it is not feasible to rationalise the number of alarms, that is, to put an upper limit to the maximum of triggered alarms. The challenge of finding some optimal range of alarm sounds, however, should be part of the alarm fatigue debate, at least as long as the problem is articulated as a direct consequence of the *sheer number* of alarms.

## Alarm fatigue in the post-mediated alarm phase

Now, if we for a moment adhere to the behaviouristic paradigm of alarm fatigue research and join the search for an explanation for missed responses of clinicians to alarm sounds, it is an unanswered question as to which potential influential parameters (if any) pertain to the other side of the alarm mediation cleft. We believe that some of the issues that are pertinent in the alarm design literature have obvious relevance to the alarm fatigue issue. While cutting down the sheer number of


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alarms may improve the situation and will certainly help with some issues, such as masking of one alarm with another, other issues may remain. Here we review three of those possible issues. These are (I) urgency, (II) sound type and (III) heterogeneity in design.

One of the key aspects of alarm design research has been that of 'urgency'. The experience of the second author is that one of the first responses to any newly designed set of alarms is that they are often regarded (by the end-user) as being 'too urgent' or 'not urgent enough' – in other words, that the match between the acoustic properties of the signal which will be used to signify its referent is inappropriate in some way. Here, the users are telling us something very clear about the relationship between one side of the cleft and the other, and the way in which they would like it to be addressed. They are suggesting that the acoustic urgency of an alarm should in some way match the urgency of the situation, achieving 'cognitive compatibility' or stimulus-response compatibility (Proctor & Reeve, 1989). It may be that alarm fatigue is partly caused by this mismatch. First, alarms typically tend to be more acoustically urgent than is necessary, by virtue of being too loud, too high-pitched, too insistent or through possession of some other unfavourable acoustic quality. This comes about partly because there are so many alarms (so they get louder and louder in order to be audible), and partly because the traditional view of alarms is that they have to startle the listeners in order to get their attention (which may or may not be true). The sheer physical impact of these adverse acoustic properties is likely to contribute to alarm fatigue, as certainly the adverse effects of noise are thought to be part of the syndrome. Second, at a more cognitive level the potential mismatch of urgency between the alarm itself and the situation it signals can cause unnecessary confusion, or at least not help the listener. For example, Momtahan, Hetu and Tansley's study (1993) not only demonstrated that fewer than half of the alarms used in the clinical environment were unrecognised by clinicians, it also demonstrated that some of the alarms which were unknown also had high levels of acoustic urgency. This means that the clinician has to work out what the meaning of the alarm is and reclassify the alarm and its significance once its meaning is known, while also dealing with the irritation caused by the overly urgent alarm. At least if there is a match between an alarm and its significance, one level of decoding is removed, thus reducing the cognitive burden on the clinician.

The idea that steps 1-4 can be reflected in some way by what happens in stages 5-8 is acknowledged and has triggered a great deal of research on the relationship between sound parameters and perceived urgency (Edworthy, Loxley, & Dennis, 1991; Guillaume et al., 2003; Haas & Casali, 1995; Haas & Edworthy, 1996; Hellier, Edworthy, & Dennis, 1993) as well as on the mismatch between clinical situations and alarms (Mondor & Finley, 2003; Momtahan, Hetu, & Tansley, 1993). It is possible to some extent to match the urgency of the alarm signal to the medical urgency of


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the signal in either a static event (for example, with a high urgency alarm for a cardiovascular event as standard) or a dynamic event (for example, where the urgency of the auditory signal varies as the monitored event changes in status), though there are still few examples of this in practice. Our ability to tackle this problem will be greatly increased by those measures currently being taken to simply reduce the number of alarms.

Following on from this, the issue as to which kinds of sounds to use as alarms feeds into this same argument. The concept of urgency arises largely from the consequences of using abstract alarms where there is no conceptual link between the sound and the situation it is signalling. Research shows that it is typically quite difficult to learn the meanings of those types of sounds (e.g. Ulfvengren, 2003). Therefore, urgency mapping may be a helpful cue in determining the listener's tendency for action. Alarm fatigue may be partly caused by the difficulties in understanding the meanings of the alarm sounds. However, some types of sounds are much easier to learn than others. Many studies demonstrate that sounds which have a much closer metaphorical relationship with their referent – for example, using a drum as a cardiovascular sound, the sound of tires skidding for a brake alert or a cough for danger – are very easily learned (Belz, Robinson, & Casali, 1999; Edworthy et al., 2014; Graham, 1999; Perry et al., 2007). Since at present no sounds like these are used in clinical environments, we do not yet know how the combined effects of ease of learning and the use of everyday sounds (which are not likely to be heard in a clinical environment) can contribute positively to the alarm fatigue issue.

Third, alarm sounds are typically very homogeneous in terms of design. For example, the audible alarms supporting IEC 60601-1-8, the current global medical alarms standard, are similar in every way, except that they are represented by different tonal sequences. They all have (or can have) the same acoustic structure, they all have the same number of pulses, and they share the same rhythm. This makes them very difficult to learn and remember, even after having been exposed to the sounds many times (Atyeo & Sanderson, 2015; Edworthy et al., 2014; Sanderson, Wee, & Lacherez, 2006; Lacherez, Seah, & Sanderson, 2007; Wee & Sanderson, 2008). Other sounds used in clinical care are typically also tonal, usually consisting of a series of beeps or pulses. This homogeneity in design may also contribute to alarm fatigue. Whilst using different types of sounds may make learning and remembering easier, it has also been demonstrated that simply increasing the acoustic diversity of a set of alarm sounds will improve the ability of listeners to tell the sounds apart (Edworthy et al., 2011). In the animal world acoustic diversity is found in individual alarm calls (e.g. Flower, Gribble, & Ridley, 2014); that is, alarm calls are varied presumably with the intent of encouraging dishabituation (the initial response is re-stimulated). In clinical or indeed any environments where humans are expected to respond to alarms individual alarm sounds are usually not varied. However, if


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habituation lies at the core of the problem of alarm fatigue, it may be useful to employ (slight) acoustic variation even at the level of each individual alarm sound.

## Methodological implications

The signal-focussed and medium-focussed approaches to alarm fatigue have quite different methodological implications. The cry wolf rationale suggests that some instances of alarm fatigue (i.e. a missed response) is due to something that happened in a not so recent past (days, weeks, months, years before), as building up a tendency to display probability matching takes time. Alarm fatigue in this sense is an expression of learned behaviour, of conditioning, and nothing in the present moment causes the behaviour except for the recognition of the alarm sound. This makes it challenging to find a suitable method to provide evidence-based knowledge of the theory.

The medium-focussed approach to alarm fatigue is better suited to providing evidence-based knowledge to document missed alarm responses and their causes. Suggestions of potential acoustic influences on alarm fatigue such as the ones proposed above can be investigated within a temporal frame in which cause and effect (supposedly) occur in close temporal proximity.

One pertinent challenge that is rooted in current alarm fatigue research is to solve the problem of clarity about clinicians' alarm exposure. There have been numerous efforts to measure and annotate the number of alarms at hospitals (e.g. Cvach et al., 2014; Drew et al., 2014). In these kinds of studies the alarm exposure of the individual clinician is typically not examined. In the before-mentioned study by Drew et al. (2014) the total number of alarms (auditory and visual) at 77 beds was measured in the course of one month. Though being a useful *indicator* of the scope of the problem in designated areas of the ward, the study does not give a very exact picture of which people were exposed to which and how many sounds, let alone how they experienced the alarms.

It is complicated to get a picture of the personal soundscape of clinicians by recording the sounds from various static points in the ward, since they are moving around a lot in the ward during a shift (to collect supplies and equipment, to assist others etc.). Even if a clinician would remain at one bed throughout the shift, he or she would not only be exposed to the alarms coming from his or her own patient, but also from alarms from other parts of the ward (of course depending on the architecture of the ward).

To retrieve knowledge of the personal alarm exposure one must know the spatiotemporal trajectory of the individual clinician and how that trajectory is within reach of alarm sounds. Accordingly, a methodology suited for knowing the alarm


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exposure of an individual clinician must necessarily provide a possibility for tracking the 'auditory spatiotemporal trajectory' (AST).

In an ongoing study on alarm fatigue (Kristensen et al., 2015) we are monitoring the AST of different nurses who work together in the ICU. Technologically, the measurement of the AST is quite straightforward. The nurses are providing us with binaural recordings (from ear-worn microphones) from a number of 12-hour shifts. These recordings give us a very precise idea about exactly how many alarm sounds they are exposed to during a shift, and importantly also the quantitative characteristics of the alarm exposure (e.g. the number and types of alarm sounds, the temporal distribution, loudness). The hard challenge is to relate the objective data (the sound recordings) with the nurses' subjective experience of the data – to make it clear how their *auditory objects of interest* (AOI) relate to the AST of the nurse. Obviously sound exposure does not equal hearing, and as discussed in many acoustemological studies (e.g. Clarke, 2005; Gaver, 1993; Schaeffer, 1966) *hearing* itself is problematic to characterise in a way that adequately represents the diverse nature of the phenomenological experience of sound.

Another challenge involved in capturing the subjective soundscape experience of individuals is to avoid a recall bias, which has been mentioned as a problem in (general) fatigue studies using self-reporting (Whalen et al., 2001). Obviously, ICU nurses who have been working for 12 hours cannot be expected to recall with great accuracy how they experienced specific episodes during the shift.

The method of 'contextual inquiry' (Beyer & Holtzblatt, 1997) has been used in observational research to retrieve detailed and context-specific information about alarm users' response to alarm sounds (Jansen et al., 2014). By interrogating the alarm users while they work this method allows the researcher to have spontaneous questions answered instantly.

In our study we are using the method 'subjective evidence-based ethnography' (Lahlou, 2011) to interrogate ICU nurses about selected episodes from their work on the basis of their own first person video recordings. This method leaves time to carefully analyse the situation and prepare questions about perspectives and details that time will not allow the online interrogator to consider. Furthermore, the scenes can be paused and replayed and thus withheld in the consciousness of both researcher and participant for as long as necessary.

## Towards a heterogeneous account of alarm fatigue

In this article we have critically examined the underlying rationale of the uniform narrative on alarm fatigue with the aim of pointing out themes in the broader alarm literature that could be fruitful sources of inspiration for methodological innovation in future research. A fundamental problem in the literature is, as we see it, that


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the problem of alarm fatigue is articulated too narrowly and based on inferences that have not been justified with sufficiently strong evidence. If instances of alarm fatigue can be inferred simply on the basis of observations of missed responses to alarms, then it is not clear to what extent clinicians experience alarm fatigue because of the false alarm signal per se, the acoustic exposure per se or an interaction effect between the two sources.

If alarm fatigue relates to the signal only (i.e. irrespective of the characteristics of the alarm sound), it should play no role as to exactly which sound is used to mediate the alarm. A logical consequence of this stance is that a high number of alarms going off would not be a problem, given that the alarms were all true positives. Research on the (psycho)acoustic consequences of designing alarm sounds, however, suggests that a number of problems in the post-mediated alarm phase could cause alarm users to fail to respond appropriately to their acoustic environment. Some of these problems, as discussed in this article, could be related to urgency, sound type and heterogeneity in design.

The problems related to the pre-mediated and post-mediated alarm phases are different in nature, but have the same potentially critical outcome: a lack of intended compliance behaviour. The problem of alarm fatigue is, thus, to some degree a conceptual problem; it lacks clarity of its constituent parts. We have presented a basic working model to characterise the (skewed) focus of the literature as such. In order to get a fuller picture of the heterogeneous nature of the problem a much more fine-grained conceptual framework is needed, by which the problem can be systematically broken down into different components and perspectives.

In addition to the conceptual problem, the construct of alarm fatigue poses an epistemological challenge. Alarm fatigue seems to be acknowledged as a mental phenomenon in the way it is depicted in the literature. Yet it is approached in a behaviourist manner; what goes on in the 'black box' of clinicians when dealing with alarm management does not seem to be of primary interest. As a consequence, it is impossible to say what exactly caused some clinician to manage some alarm in a specific way. The epistemological change, from an *etic* to an *emic* approach, seems however to be underway. For instance, Deb and Claudio (2015) recently made an observational study of alarm fatigue in relation to individual differences of staff members and their working conditions. The challenge in a study like theirs is to find appropriate tools for characterising the construct of alarm fatigue. In the literature on fatigue (in general) an abundance of questionnaires and measurement scales have been developed over the last century for different kinds of fatigue in different settings and conditions (for a review, see Christodoulou, 2005). The same kind of methodological innovation (or at least inclusion of new methodologies) is needed for the particular kind of fatigue that *relates to sound*.


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Currently it is of high priority in the medical world to develop a quantitative definition of alarm fatigue and proper metrics to measure (Deb & Claudio, 2015). On the basis of the arguments presented in this article we believe that an equally (if not more) important agenda is to produce evidence-based knowledge on alarm fatigue that is based on qualitative analytical diversification of individuals' sound experience. For this agenda it is relevant to include more work from humanistic domains like acoustic ecology (e.g. Schafer, 1977) and semiotics (e.g. van Leeuwen, 1999) that provide tools to stratify and diversify the listening experience. In a criticism of musicological discourse at the time, Cook (1998, p. 4) stated that 'musical meaning is all too often discussed in the abstract, rather than in terms of specific contexts, as if it were somehow inherent in the "music itself" regardless of the context of its production and reception'. A similar credo is necessary to take on in the study of alarm fatigue if we want a more heterogeneous account of the phenomenon with knowledge about how clinicians in a specific culture, under specific working constraints and at specific times deal with the exposure to specific alarm sounds.

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