COMMUNICATIVE FUNCTIONS OF SOUNDS WHICH WE CALL ALARMS

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ABSTRACT

The design of alarm or warning sounds appears to be far from a trivial challenge. Even if the basic principles of creating an alarming quality for a sound have been widely accepted and applied, there seems to be a constant need for knowledge about what a "good" alarm should sound like.

In this paper, we analyse the challenge of alarm sound design. The analysis is carried out in terms of an application context, which is an anaesthesia workstation in an operating room. We conclude that to result in satisfactory sounds, the design should not only concentrate on stereotypic qualities of expected alarms, like a strong psycho-physiological reaction but should also take more aspects into an account. It is proposed that these context dependent aspects, in turn, are extracted from the communicative functions of the sound's intended usage. For such a conceptual design of alarm sounds, a basic taxonomy of communicative functions in terms of alarm priority levels is proposed.

Even though this report concentrates on one application area, the approach would be applicable in several areas. Sound design for other safety critical applications, in particular, would benefit from our findings.

Keywords: warning sounds, anaesthesia, communicative functions

1. INTRODUCTION

What does a "good" alarm sound like? When analysing alarm sounds or warning sounds, the design has actually started when the object of design is called an alarm or warning. The foremost communicative function of the sound to be designed has been embedded in that term.

In terms of communication, warning or alarming someone has a fairly self-evident function. When we warn, we wish someone to become aware of a danger or a risk. However, by performing a warning, e.g. by shouting or by hand gestures, we more or less inadvertently affect the person we are warning. For instance, we might startle or even frighten him or her. Or then, if the person to be warned feels that the warning was unnecessary, he or she might find the warning irritating or disturbing. Our warning may also be received by other people, for whom it is not at all relevant.

The description above can be applied to practically any context. In everyday life, we are used to false alarms or alarms which can easily be classified as irrelevant. In safety critical contexts, however, the requirements for warnings are much higher. While in some contexts, a strong and rapid reaction is all that counts, in safety critical environments the appropriateness of the reaction may be much more important than its strength of it [1]. Even though we talk about warning sounds, when hospital equipment is concerned, sometimes the primary function of these sounds is not necessarily to warn, but to inform [2]. However, this is not an either-or matter, since sounds can easily serve multiple functions. For example, vocal warnings vary in different situations, often telling us more than just that there is a danger, thus providing a basis for an appropriate reaction. We see that awareness of these varying communicative functions in regard to a given alarm condition, would enable the sound designer to formulate the design principles in a context-tailored manner.

Alarm sound studies traditionally concentrate on qualities like reaction time or perceived urgency. Indeed, these issues are important in the design of alarms. The studies in this domain have resulted in practical guidelines for alarm sound design (e.g. [3, 4]). The problem is that these guidelines mainly focus on communicating the urgency, thus acknowledging the alarming function of sound only. The second problem is that guidelines never cover all qualities of sound. They may provide details about intensity, frequency or rhythm, but many decisions about what the sound will actually sound like (qualitatively) are still left to the intuition of the individual designer.

In the current paper, we report a study in which we analysed the communicative functions of alarm sounds and some other non-speech sounds of an anaesthesia workstation in an operating room (OR) context. In the study, human expressions relating to each communicative function were used as a basis for the alarm sound design process.

2. DESIGN CASE: ANAESTHESIA WORKSTATION

The underlying purpose of this study was to find relevant and adequate information for the needs of designing a number of alarms in an anaesthesia workstation. Even though we focus on this particular case, the method and the underlying approach would be applicable in most applications of non-speech user-interface sounds, in particular in safety-critical contexts. For meet the brief of the current study, we needed to start by familiarising ourselves with the OR conditions, with particular regard to the soundscape. In an OR, there are numerous gadgets which all have their own repertoire of alarm sounds. A mayhem of different alarms is guaranteed when the room is equipped with technology made by different manufacturers, all of whom have their own product in mind alone when

This work is funded by Finnish Funding Agency for Technology and Innovation (TEKES), and the following partners: GE Healthcare Finland Ltd., Suunto Ltd., Sandvik Mining and Construction Ltd. and Bronto Skylift Ltd.

designing it. The hard acoustic properties of a typical OR, caused by the interior surfaces which have primarily been chosen for hygiene, do not make the situation any easier.

2.1. Method and procedure

Our research method was based on the so-called Rich Use Scenario (RUS) method, which has been created to understand the essence of the context of use for the needs of design [see 5, 6]. The application of RUS was modified for the current context.

The RUS method is based – as the name indicates – on use scenario. Typically, use scenarios are condensed descriptions of a use of an application [7]. They are used to reveal use-related issues, which would otherwise remain unnoticed. RUS differs from traditional use scenarios in that its focus is not on the observable details of use – like in overt behaviour – but on the experiences of the user, as a person. In RUS, the aim is to provide inspiration for designers. Therefore, RUSs are lively stories, which provide vivid imagery of the flow of using the application. The listener or, depending on the form of implementation, possibly, for example, the reader of the story, should be able to identify her or himself with the character(s) of the story. The technology to-be-designed is part of the environment which that person is living in and interacting with. The method has previously proved to be an effective way of immersing oneself in the context of use, from the user's point-of-view [6]. The story provides a common ground for a multidisciplinary team to reflect their design ideas. Programmers, graphic designers, interaction designers or other experts are thus able to justify their ideas within a common framework, which is understandable for the whole team: The team members ask themselves "How would the character experience this or that idea".

In the current case of an anaesthesia workstation, RUS took the form of a radio-play. The radio-play has proved to be an ideal form of implementing a use scenario for this kind of purposes, since:

- The whole design team is concentrating on each and the same point of the story at a time. In a written story, each member of a group would be at a different point of a story at a given point of time.
- The radio-play has been found to be an effective way of focusing the attention of group members [6], as well as evoking creative ideas (compared to video [8])
- As RUS provides a projection of the application use through the experiences and actions of the user, omitting visual elements in storytelling arguably facilitates the group participants' use of imagination and helps the "enacting" of those experiences by themselves.
- As a form of presentation, audio is well suited for brainstorming sounds.

The alarm sounds, which were the actual object of interest, worked as sound effects in the radio play. The process, in brief, was as follows:

1. The manuscript for the radio-play was prepared in cooperation with the experts in the context (usability experts of the manufacturer).
2. The radio play was implemented. In the radio play, the sounds-to-be-designed appear as points of "missing" sound effects, allowing them to be imagined.
3. Two design panel sessions were organised. The participants were six students of different subjects at the University of Jyväskylä. However, none of the participants had medical science as a major subject, i.e. the participants were amateurs in terms of the context. In the sessions, the participants planned and implemented appropriate sound effects at the given points of the radio-play (which were sounds from the anaesthesia workstation).
4. On the basis of the work of the non-expert design panels, draft sounds were implemented and embedded in the radio-play.
5. Two expert panel sessions, each made up of two anaesthesia nurses and one doctor, were conducted. In the sessions, the final radio-play, including the sound effects, was listened to and discussed.
6. A post-questionnaire was sent to all expert panel participants.
7. The discussions of the expert panels were transcribed and analysed.

The RUS manuscript and its radio-play implementation worked as input for the preparation of draft sounds in a non-expert design panel. The radio-play, with draft sounds included, provided a basis for the discussions of the expert panels. Draft sounds especially worked as effective "triggers" of conversation.

The decision to ask non-expert panellists to produce the draft sounds was found successful. In the previous versions of RUS, the production of draft sounds was found to be problematic [6]. We conclude that our previous parallel between draft visual layouts and draft UI-sounds was not appropriate. In visual mock-ups, draft quality has been found to encourage the users to make suggestions. Possibly, the power of draft quality (especially hand drawn) is not in its coarseness *per se*, but in the "human touch" – the panellist/designer can easily attune to the outcome and imagine having produced the draft by herself. The draft sounds we have previously used were produced with a computer, and they always contained some qualities so irritating that they did not provide a basis for constructive elaboration. However, while this time used human voice and real instruments, the sound idea was much better communicated.

The outcome of non-expert panels clearly illustrated the sound ideas of the panellists. In the case of alarm sounds, we took recurring ideas from various different draft sounds and arranged these features into one coherent sound set. All new draft sounds were re-articulated with the same instrument (metallophone), except sound #4, still trying to preserve the characteristics of the original draft sounds produced by the non-expert panellists.

2.2. Analysis

This report focuses on the analysis of the discussions of the two expert panels (phase 5 above). It has to be noted that the discussions were originally in Finnish, but we have tried to express the original nuances when translating the quotations in this report into English. When the discussions contain oral expressions of non-speech sounds, we use phonetic notation.

The current analysis concerns four different sounds in different alarm conditions, which represented different levels of warnings in the anaesthesia workstation. The radio-play used in panels dealt also with some non-alarm, non-speech sounds for the anaesthesia workstation, but they are not included in this analysis.

2.2.1. Sound #1: Medium priority alarm

The draft sound was produced with a metallophone. It consists of series of two damped hits at approximately 1 sec. intervals (D# tone, medium register).

The events causing the alarm condition in the scenario were:

- Blood pressure has exceeded the alarm level (patient based alarm)
- The entropy meter is badly connected (device based alarm).

General observations concerning design principles:

- In expert panel 1, the events of the scenario were found different in priority:

> ...but I think that if blood pressure has really been too high, it is quite different and requires different reaction than a badly connected entropy sensor – if it has not been pushed in tightly enough thus losing contact.

- Expert panel 2 wished medium-level alarms to be merely informing rather than alarming:

> ...It has to be noted, that 'aha', but not anything more severe, let's sign for it in a few minutes. But if you are busy with other, important tasks and that is tapping away all the time in the background, it would rile.

> ...it obviously depends on the scale – what is classified as important.

Opinions about the draft sound:

> ...Perhaps a bit too feisty...kind of loose...

> ...should not be that dense...

> ...I don't like that metallic tone, it's irritating...

> ...[should be] somehow softer...

> ...Were there two taps? Perhaps rather...well it depends on the qualities of the sound but perhaps one of that kind would be good.

> ...since there were two of them [taps], it made it kind of commanding, like 'hey, ... !!'

Features of the sound:

- Medium-level alarm should not be too loud, obtrusive nor frequent.

> ...perhaps high priority alarm should be something like this (tapping continuously) to grab attention, but these kind of sounds in which no immediate reaction is necessary, perhaps simple [ˈbø:b] would be adequate.

- On the other hand, it should be snappy and adequately startling.
- Soft, non-metallic timbre would be desirable.
- Single-tone structure (instead of two tones) and longer pause between repetitions (at 10-15 sec intervals) was proposed.

2.2.2. Sound #2: Low priority alarm

This draft sound was also played with a metallophone. It consists of single damped hits at approximately 2 sec. intervals (F tone, low register). The alarm condition in the scenario was due to the sensor for muscular activity becoming loose (device based alarm).

General observations concerning design principles:

- Low priority alarms should not be alarming at all:

> ...Well, you know, that when you hear those day after day...if a...I wouldn't say unnecessary but a less urgent issue causes extremely...is very strong, it drowns everything else.

- The conversations indicated that frequent alarms and the kind of alarms which are perceived as ”cry wolf”, should preferably be totally removed.
- To be meaningful, a low priority alarm should only inform, without demanding too much attention and rapid reaction. It can be repeated, not too frequently, but as a reminder.

Opinions about the draft sound:

> ...Not too bad. Quite sharp, though. But as a form of sound, not bad.

> ...Could be a bit softer...

> ...That the device has come loose, that is quite...working, not bad.

> ...Quite suitable pause between the sounds, so at least I didn't find it...

> ...At least there is no need for more frequent repetition, because it is not a question of something fatal...but you just pay attention, 'aha'

> ...I would draw the scale [of alarming] downwards.

> ...This sound, caused by such a minor issue frightens the patient needlessly...if I was there and heard such a sound, I would be astonished, asking if there is something badly wrong with me. And that is unnecessary from all points-of-view.

Features of the sound:

- Quite similar to the medium priority alarms, but low priority alarms especially should be soft reminders.
- Short, sharp sounds should be avoided. Since it is a question of an infrequently repeating sound, its duration may be longer with a soft onset.
- 5-10 sec was found to be a suitable interval between the repeating sounds, when different intervals were compared. (It has to be noted that the comparison was focused on the sound, and therefore very different from the real situation.) With a slower sound onset time, it was proposed that the interval could probably be even longer.

In other words, the underlying *action model* for sound design could be, for example, ”peaceful breathing” rather than ”hitting”.

2.2.3. Sounds #3 and #4: High priority alarm

For this case, two draft sounds were produced. The first one was intended as a patient based alarm. It was played with a metallophone, consisting of rapid bursts of two hits repeating at short intervals (G# tone, high register). The second draft sound was proposed as a device based alarm. It was implemented by stomping with feet in rapid three-hit bursts repeating frequently.

The events causing the alarm condition in the scenario were:

- False alarm / noise in EEG, caused by diathermia (patient based alarm)
- Battery running out (device based alarm)

General observations concerning design principles:

- The panellists found alarming qualities important in high priority alarms, when it is a question of a critical situation which requires immediate reaction. In such a case, the sound can and should be ”irritating”.
- There may be differences among well functioning alarm sounds in terms of their pleasantness. In the panel, the draft sound was found to be alarming but also more pleasant than the sounds of the existing product.
- The draft alarm sound for a low battery level was implemented differently from the previous one, thus illustrating the difference between patient and device based alarms.
- Some of the panellists also ideated a continuous, non-critical warning sound which could be on whenever the device is running on batteries. It illustrated the possibility of providing information about the condition *gently*, before anything wrong happens. Low pitch and the soft clicking tone can be used to avoid excessive obtrusiveness, which would shift attention from critical issues.

  > . . . Our nitrogen servo always comes to mind . . . namely that when you inspect it, you will need to unplug it from the mains. So when it is running on batteries, it continuously makes a sort of low, ‘clicking’sound [ˈnɑkˈnɑkˈnɑk] – so you are bound to notice that it is running on batteries, without mains.

Opinions about the draft sounds:

- Patient based alarm (#3):

  > . . . If there really is a tachycardia or asystole, this sound would turn the head, ‘what’s going on’. But for a fault caused by noise, that is. . . no thanks!

  > . . . I wouldn’t call it bad at all. When urgent warning qualities are needed, this works. . .

  > . . . I found this quite good.

  > . . . I think that this one had the most pleasant tone of these, I don’t know what makes is pleasant though.

- Device based alarm (#4):

  > . . . I found that good. It was so different from the other sounds. Quite. . . ok.

  > . . . There are so many tonal sounds in use. Once when we were urgently trying to find which meter was screaming or whose device was beeping. . . , it was revealed that the sound source was actually a refrigerator, indicating that it is freezing something. . . So that kind of distinguishable sound is really relevant.

  > . . . I found it good that there was a short interval.

  > . . . It came through like [ˈkɒpsˈkɒps] screaming that ‘there is a failure, there is a failure’

  > . . . And it was different, so that you will react differently, go to the device to see what’s wrong.

Features of the sound:

- Expert panellists approved both sounds as very good alarm signals for a critical situation that needs immediate care.

  > . . . I find the distance between two pairs [bursts] most important. It has to be short. . .

  > . . . those two hits. . . they should not be too far away either, to make the sound almost continuous

  > . . . This was good in both ways, both the distance between the pairs and between the single sounds of a pair.

  > . . . I think that there wouldn’t be anything wrong with either of these high priority alarms. They could be adopted just as they are now.

- Even though the sound for patient based alarm was produced with the same instrument as the previous alarms (whose timbre was not found pleasing), metallophone was now found appropriate and even pleasant.

  > . . . In my ears, that did not sound like the same sound being played more frequently. Rather, there was something more pleasant and it was getting attention quite well still.

  > . . . In my own mind, based on previous experiences, I associated this with an alarm of a train which is soon departing, meaning that you have to hurry now.

2.3. Summary of findings

2.3.1. Features of draft sounds relating to the alarm priority categories

In general, in the sound ideas of the non-expert panellists, the intended alarming quality was produced with a repeating series of two or three beats. These ideas came up spontaneously, from several panellists, even though there were no external cues (e.g. in the instructions) for this kind of structure. Another common feature among the proposed series of beats was that they did not constitute any melodic structure, but were repeated at a constant pitch or were percussive. It could thus be interpreted that a melodic alarm or warning (suggested in IEC/ISO 60601-1-8, annex F) would not be very intuitive. This conclusion is also supported by the observation that the same panellists proposed melodic features for non-alarming sounds, as well as previous studies [9].

The absolute pitch of the proposed alarm sounds varied, as well as the timbre and sound source (vocal sound, metallophone, xylophone, foot stomping), while the basic idea of an alarming quality remained the same. As explained above, for the needs of the expert panels, the ideas of the non-expert panellists were summed and reproduced in a newly articulated set of draft sounds, which was in accordance with the alarm priority scale.

In high priority alarms, the series of two or three beats/notes appeared in dense bursts (onset distance approx. 80-180 ms). In addition, the bursts were densely repeated (interburst interval approx. 300-700 ms). Within an articulation, these gaps between beats and bursts remained consistently the same. In medium level alarms, the beats or notes (one or two) were articulated more calmly (onset distance approx 400 ms) and with less intensity. In addition, the frequency of series was lower (interburst interval approx. 1,2 s) and generally produced with lower pitch than high priority alarm sounds. Low priority alarms were characterised by low frequency and a softly articulated structure of one beat or note (interburst interval approx. 2 s).

It has to be noted that the way in which the alarm priority levels appear in the ideas of the non-expert panellists' draft sounds, corresponds amazingly well with the IEC/ISO 60601-1-8 standard (see especially tables 3 and 4 on page 35), which is mainly based on rhythm. The clearest difference between the draft sounds and the standard was in the distance between bursts, which are defined as much longer in the standard than the panellists proposed. An exception to this is the high priority alarm given in the standard, in which one burst consists of four rapid sub-bursts. So the alarm defined in the standard consists of very rapidly repeating sub-bursts, but only in periods of two.

In terms of the rhythm, it can be summed up by saying that the difference between the draft sounds of the panels and the ISO standard was that the draft sounds were more alarming by nature. One likely reason for this was the non-expert panellists' lack of experience of the context of use. Another possible reason is that the straightforward naming of sounds as "alarms" – even in the case of low priority – might have stressed the need for alarming communicative function. However, generally speaking, the professionals appeared to prefer the spontaneously produced draft sounds of the panellists to the existing sounds of the workstation, even though the latter ones follow the standard.

2.3.2. *Expert panels' assessments of the alarm priority levels and draft alarm sounds*

As a rule, the panellists found that there are too many alarms in an OR or they are seen as irrelevant. On the other hand, it was admitted that most of the alarms are necessary. The key issue is the way in which different alarm conditions are classified into the three alarm categories. It was claimed that only in conditions which are really urgent should be alarming by nature. It was wished that medium and low level alarms would be merely informing or reminding. Since the conditions in those cases do not require immediate reaction, too alarming a sound would disturb the ongoing work.

Our interpretation is that the biggest challenge in alarm sound design is not the design of high priority sounds, in which even extremely alarming sounds are found as appropriate. On the contrary, the challenge is in the design of low and medium level alarms, which are usually experienced as too frequent and too strong in terms of the alarm conditions.

> . . . Those are always the ones we try to switch off, because there is the risk that you become deadened to the constant alarm, and don't pay attention to a real one. So we try to adjust the alarm threshold values and other things so that – when there is a real change. . . If the patient's blood pressure is high, say, 200, we raise the alarm threshold value so that only if the pressure gets even higher, there is an alarm. But not constant alarming, as told, because then you might not react.

> . . . All the kind where the patient's life is under immediate threat, then of course, not when the importance and message is that we anyway act in five seconds, so it doesn't have time to irritate. The issue is fixed or switched off. . . it overrides everything else. . . and it won't have time to irritate.

> . . . In quite many cases it is a question of a situation like 'oh no, that started to alarm and interrupted what we were just doing. . . '

> . . . it would be good to have an alarm if it is detached from the hoses , of course, but anyway, you won't die in a second if it is detached like this; but those real alarms should engage only when they are definitely needed.

> . . . [medium and low priority] issue and message is heard and noted and reacted to as soon as it is possible. However, when that 'as soon as possible'moment is there, the alarm should not hinder action by irritating and by preventing concentration.

So it can be argued that the communicative function of low and medium level alarms should be informing and reminding, rather than alarming. They differ, however, from information signals (as referred in ISO standard) in that they anyway relate to alarm conditions and should be interpreted in that context. Low and medium level alarm signals were seen in quite a similar way in similar functions: soft informers and, when needed, reminders of an alarm condition. In a post-questionnaire, all 6 panellists agreed that three alarm priority levels are appropriate, but most of them (4) added that existing alarm sounds have more alarming qualities than necessary. According to the panellists, this is mainly due to inappropriate illustration of the intended priority level in the sounds, rather than inappropriate prioritisation of alarms. Both of these – the intended prioritisation and the one perceived – should be critically considered.

Even though it could be argued that the draft sounds which we used in the expert panels are more alarming than what the ISO standard suggests, they worked quite well as a part of a contextual, radio-play format scenario. High priority alarms were found appropriate and even pleasant. Their division into patient and device based alarms received positive feedback. In low and medium level alarms there was a wish for a different character. Apparently, using the metallophone in all sounds was not a very good idea, since the sharp and metallic tone was found appropriate in high priority alarms only. In contrast, in low and medium level alarms, panellists wished the "scale of alarmness" to be downgraded. There was a desire for softness in tone and in onsets and offsets of sounds.

Medium level alarms were also found too "dominant" and the sequence of bursts too frequent. In the low level alarm the sound was also found to be repeating too frequently. When different intervals between the repetitions were tried out, 5-10 seconds seemed appropriate, but 10-20 seconds was found too long (according to the ISO standard, in a low priority alarm the interval should be 15 seconds). It was mentioned, however, that if the sound were longer with soft rather than sharp onset and offset slopes, the interval could be longer. The panellists never argued that even the low priority alarms were completely unnecessary. However, expert panel 1 wished the regular measurements of blood pressure and the sounds of the pulseoximeter to be removed:

> ...it does not need to tell us every five minutes that now blood pressure has been measured...

As mentioned, alarms were considered to be necessary, but negative attitudes towards the existing alarms were expressed many times. What is so irritating in the existing sounds? One possible feature is that they are felt to be artificial and machine made:

> ...I have to say that the current sounds, they are clearly kind of mechanical, mechanically created sounds, so they are not...and these [draft sounds of the scenario] have been produced somehow with natural instruments.

> ...Or stomping with feet or something...these sound somehow more pleasant than those kind of...

> ...[the current alarm sound] sounds kind of stuffy imitation, while that [draft sound] is clean and clear...

In the post-questionnaire, most of the panellists (4 out of 6) wanted primarily to change the timbre of the existing alarm sounds. The other two panellists, respectively wished to change the characteristics or repetitions of the alarm sound. Obviously, recurrent exposure to alarms and the above-mentioned discrepancy between alarm priorities and alarm signals also has an effect on irritation.

In the current alarm sounds, the alarming quality has been designed by defining the technical parameters of sounds. ISO standard's guidelines encourage mechanical production of sounds in which certain parameters fall in the recommended range. However, the standard does not handle a sound *per se* as a meaningful and intentional object. We thus propose that the level of alarmness should be seen as a communicative function, mediated by the alarm signal, rather than just technically scaled features of sound. Communication is mediated in the amateur panellists' and sound designers' draft sounds in a natural way – through the spontaneous articulation of intention. More attention should also be paid to the acoustic characteristics of sounds and various connotations and affective reactions evoked by them. Perhaps the metallophone, which was used in the articulation of draft sounds, has not enough expressive power since it is not possible to make many adjustments to its timbre, duration or the internal dynamics of the sound.

2.3.3. Division into patient and device based alarms

As previously mentioned in this report, the expert panels participants found the division into patient and device based alarms a good idea. In panel discussions, the panellists encouraged the making of this division in forthcoming alarm sounds. It was found important that the sound itself (e.g., its timbre) should indicate the source of alarm. This appeared to also a priority or emergency issue. The post questionnaire showed that the panellists were not concerned about the growth in the number of different kinds of alarm sounds resulting from this division, but they believed that the division would make the interpretation of different sounds easier.

A device based alarm was seen as lower in terms of priority than a patient based one. Since both of the alarm types need to be interpreted with the same priority level scale (low, medium, high), the alarms within each category need to resemble each other to some extent. For instance, the rhythmic structure could define the priority level category, while tone could be used to make a difference between patient and device based alarms; device based alarms tone could be less alarming (soft, damped) and patient based, in turn, clearer and sharper. This difference could be seen in the high priority draft sounds, in which the device based alarm was produced by stomping feet and the patient based with a metallophone.

3. CONCLUSIONS AND DISCUSSION

Since the categorisation of alarm conditions and related alarm sounds into three priority levels has been found appropriate, the focus of sound design should be on the design of appropriate sounds for each level. The clinicians who participated in this study clearly expressed that they need sounds which would correspond better with their referents than the existing sounds of their current devices. A general principle in sound design could be that none of the sounds should feel unnecessary in its context (i.e., could be removed) nor unnecessarily strong or uncomfortable (i.e., should be removed).

According to the current standard of alarm sounds, the primary function of alarm sounds is to make the operator shift attention to the cause of the alarm (IEC 6060-1-8, p. 77). The communicative functions of alarm sounds thus mainly relate to appropriate focus of attention and indication of urgency (priority levels). We find it important to notice that the communicative functions of these sounds are not only for alarming. Even if the sounds which we dealt with in the case study have been classified as alarm sounds, the analysis of the discussions of the practitioners made us suspicious about the appropriateness of the term "alarm", at least in an OR context. When going through the use scenario and the related sounds one by one, we found that "alarming" or "commanding" was the foremost function of the sound only for high priority alarm conditions. Still, our clinician panellists acknowledged that sounds for lower priority conditions are needed mostly because of the information they provide. This suggests that their primary communicative function is informing-related (see also [2] and Table 1).

Only in truly urgent events is it justified to use alarming features in sound. In the design of lower priority level sounds, the mere mechanical reduction of alarming features of a high priority sound is not an adequate guideline. In addition to alarming and urging, other functions and means to express them should be considered in order to prevent inappropriate reaction or inconsistent associations in the given context (taking all modes of listening into account [10]). In other words, the designer needs to consider subtle ways of getting attention when it is a question of low or medium level alarms. What is subtle and what is not should be assessed in terms of the operator's experiences.

It was interesting that the draft sounds, ideated by amateurs for given situations, corresponded amazingly well with the alarm sound standard. Even if they were even more alarming than the existing sounds (which strictly follow the standard), they were found more pleasant. According to our observations, the key issues in this phenomenon were ”human touch” and communicative intention conveyed in the articulation of the sound. In music performance, articulation (i.e., how notes are expressed as sounds) is a central factor in the mediation of emotional and intentional states of mind. Likewise, we would recommend striving towards communicative expression and concentrating on the articulative nature of sounds when designing sounds for hospital technology.

The finding above fits in well with the notion of embodied cognition [11]. Since human experience is ultimately based on bodily reflections, it is more natural to interact with sounds which can effortlessly be related to corporeal events than with sounds which feel artificial [12, 13].

The design case presented in this paper provides general principles and detailed guidelines for the needs of sound design in this particular case and context. The principles, in particular, would be beneficial in other contexts as well. In terms of priority levels, the central observations could be summed up as follows:

- High priority alarms:
  - Sounds can clearly be even more alarming – in terms of perceived urgency – than the sounds which follow the standard.
  - Even if it can be assumed that there is an immediate reaction to the alarm, continuous alarm signals are not recommended. For instance, in the structure of dense bursts, there should be a pauses (e.g. as follows: 5 dense bursts – 3 seconds’ pause – and so on).
  - Melodic structures do not seem to be perceived as alarming; possibly quite the contrary.
  - Percussive sounds appear to be favoured, at least by our panels, i.e., the underlying mental model or action model is to warn by beating, stamping, knocking etc.
- Medium priority alarms:
  - The sound needs to get attention, but excessive commanding or sharp quality should be avoided.
  - One single soft sound object, repeating at about 10 second intervals, could be adequate. The alarm sound ISO standard provides an appropriate guideline for the frequency of repetitions.
  - Sound objects could be constructed in terms of the burst definition in the ISO standard. The strictly defined structure of burst should be broken up, though. Sound objects do not need to be mechanical, beeping pulses either.
  - Attention should be paid to the timbre and internal dynamics of sounds. Crucial factors in the perceived softness are onset (attack) and offset (release) phases of a sound object and the *legato* between separate objects.
  - Percussive sounds did not work in the panels. The related action model should be softer than beating, e.g. arched swing, circular movement or waves.
  - Even though it is a question of an alarm, the dominating communicative function should not be commanding or alarming, but something more subtle.
- Low priority alarms:
  - The sound should be noted, but all commanding or sharp qualities should be avoided.
  - Close resemblance to a medium-priority alarm, but more subtle, soft, ”round”, simpler in structure and more peaceful.
  - Alarming qualities – in the traditional manner – should not be included at all.
  - One single, very subtle sound object, repeating at 15-30 second intervals. The standard is a good basis for defining the interval.
  - A burst consisting of two melodic sounds, suggested by the standard, appears too obtrusive for low priority alarms.
  - Communicative intention should be to guide attention or inform with subtle, pleasant means. A commanding or alarming quality is not at all appropriate.

Table 1: Classification of certain communicative functions in terms of priority. Proposed primary functions are highlighted. Because of the sensitivity of low priority alarms, expressive functions are proposed for primary role.

	Directive functions (e.g. alarming, prompting)	**Assertive functions** (e.g. informing)	**Expressive functions** (e.g., expressing arousal or calmness)
High priority	**Urging to act right now, demanding attention**	Asserting immediate threat. Optionally informing about the cause (e.g. patient or device)	Expressing high levels of arousal
Medium priority	Asking for attention, suggesting an operator action	**Informing or giving feedback about alarm condition** (state of the patient or the device)	Expressing calmly, but sensitively implying slight arousal
Low priority	Guiding attention, implying a potential need for action	Informing or giving feedback about alarm condition (state of the patient or the device)	**Expressing gently**

As we suggest conceiving alarm sounds as communication, let us examine the communicative functions of alarm sounds within the context of speech act theory [14]. According to the theory, a speech act is directive when its intention is to get the hearer to undertake an action. Alarming and attention getting sounds thus primarily serve *directive* functions. Similarly, an *assertive* speech act, which presents some state of affairs in the world, corresponds with the communicative functions of informing. An *expressive* speech act is also very relevant to alarm sounds, as it refers to expressing the affective state being involved in the act of communication. These mentioned points of speech acts (directive, assertive and expressive) bear the closest relevance to the functions of alarm sounds, and we propose that they can be used as general top-level categories in conceptualising the spectrum of different communicative functions and their relative "weights" in each case of alarm sound design. Table 1 demonstrates how these categories can be applied in formulating design principles for alarm sounds of high, medium and low alarm condition priorities.

We argue that the naming of sounds directs the orientation of the sound designers. Judging by the experiences of the practitioners, too much alarming quality is usually included in medium and low priority alarm sounds. We argue that the key issue on the way to more acceptable sounds would be to analyse the communicative functions of each sound to be designed at the very beginning of the design process. It might be a good idea to call each sound according to its primary communicative function – calling a sound an alarm would at least sub-consciously perhaps orientate a designer to look for ways of communicating through sound that are too obtrusive.

4. REFERENCES

[1] J. Edworthy & E. Hellier, "Fewer but better auditory alarms will improve patient safety", Quality and Safety in Health Care vol.14, no.3, 212–215, 2005.

[2] F. J. Seagull, Y. Xiao, C. F. Mackenzie, & C. D. Wickens, "Auditory alarms: from alerting to informing", In Proceedings of International Ergonomics Association 2000/Human Factors and Ergonomics Society 2000 Congress, Vol. 1, pp. 223–226, 2000.

[3] R. D. Patterson, "Guidelines for auditory warning systems on civil aircraft", CAA Paper No. 82017, Civil Aviation Authority, London. 1982.

[4] J. Edworthy, S. Loxley & I. Dennis, "Improving auditory warning design: relationship between warning sound parameters and perceived urgency," Human factors, vol. 33, no. 2, p. 205, 1991.

[5] A. Pirhonen, K. Tuuri, M. Mustonen, & E. Murphy, "Beyond clicks and beeps: In pursuit of an effective sound design methodology", In: Oakley, I. & Brewster, S. (Eds.) Haptic and Audio Interaction Design. Proceedings of Second International Workshop, HAID 2007. Seoul, Korea, November 29-30, 2007. Lecture Notes in Computer Science 4813, Berlin/Heidelberg: Springer Verlag, pp. 133–144, 2007.

[6] E. Murphy, A. Pirhonen, G. McAllister, & W. Yu, "A semiotic approach to the design of non-speech sounds", In: McGookin, D. & Brewster, S. (Eds.) Proceedings of First International Workshop, HAID 2006, LNCS 4129, Berlin/Heidelberg: Springer Verlag, pp. 121–132, 2006.

[7] M. J. Carroll, Making use: Scenario based design of human-computer interactions. Cambridge, MA: MIT Press, 2000.

[8] P. Greenfield, D. Farrar, & J. Beagless-Roos, "Is the medium the message? An experimental comparison of the effects of radio and television on imagination", Journal of applied developmental psychology, vol. 7, no. 3, 1986, 201–218.

[9] P. Sanderson, A. Wee, E. Seah, & P. Lacherez, "Auditory alarms, medical standards, and urgency", In: Stockman, T., Nickerson, L. & Frauenberger, C. (Eds.) Proceedings of International Conference on Auditory Display ICAD 2006, Queen Mary University of London, June 20-23, 2006, CD-ROM format.

[10] K. Tuuri, M. Mustonen & A. Pirhonen, "Same sound – different meanings: A Novel Scheme for Modes of Listening," In Proceedings of Audio Mostly 2007 Ilmenau, Germany: Fraunhofer Institute for Digital Media Technology IDMT, 13–18, 2007.

[11] M. Leman, Embodied Music Cognition and Mediation Technology, Cambridge, MA: MIT Press, 2008.

[12] R. I. Godøy, "Gestural-sonorous objects: embodied extensions of Schaeffer's conceptual apparatus," Organised Sound, vol.11, no. 2, 149–157, 2006.

[13] K. Tuuri, "Gestural attributions as semantics in user interface sound design," In: Kopp, S., Wachsmuth, I. (Eds.), Gesture in Embodied Communication and Human-Computer Interaction, No. 5934 in LNAI, Springer-Verlag, 257–268, 2010.

[14] J. Searle, "Expression and meaning: Studies in the theory of speech acts," Cambridge, UK: Cambridge University Press, 1979.